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THESIS

DETERMINING TACTICAL USAGE OF NON-LETHAL
WEAPONS FOR FIXED SITE SECURITY
OF U.S. EMBASSIES

by

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June 2017

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13. ABSTRACT (maximum 200 words)

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1. Is the NLW effective at reducing the lethality of the situation?
2. Are there any tactical insights gained by using agent-based simulation?
3. Is there a tactical benefit to reducing the minimum engagement range for the NLW?

The results of this research indicate that having this non-lethal capability does reduce the lethality of the scenario, and all posts should carry at least two NLWs. Additionally, if three NLWs are assigned to each post, the other factors explored have little impact. Finally, reducing the minimum engagement range does present a tactical benefit, but only if reduced to less than 20 meters.

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DETERMINING TACTICAL USAGE OF NON-LETHAL WEAPONS FOR FIXED SITE SECURITY OF U.S. EMBASSIES

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ABSTRACT

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DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABM	Agent-based Model
ABS	Agent-based Simulations
AFRICOM	United States Africa Command
ANLM	Airburst Non-Lethal Munition
AO	Area of Operations
CMC	Commandant of the Marine Corps
COA	Course of Action
CSV	Comma Separated Values
DOD	Department of Defense
DMSCO	DOD Modeling and Simulation Coordination Office
DoS	Department of State
DOE	Design of Experiments
EOF	Escalation of Force
GUI	Graphical User Interface
ISIS	Islamic State in Iraq and Syria
JNLWD	Joint Non-Lethal Weapons Directorate
M&S	Modeling and Simulation
MANA	Map Aware Non-Uniform Automata
MCESG	Marine Corps Embassy Security Group
MCWP	Marine Corps Warfighting Publication
MOE	Measure of Effectiveness
NLW	Non-Lethal Weapon
NOLH	Nearly Orthogonal Latin Hypercube
ROE	Rules of Engagement
SE	Standard Error
SEED	Simulation Experiments and Efficient Designs
SPMAGTF	Special Purpose Marine Air-Ground Task Force
SPMAGTF-CR-AF	Special Purpose Marine Air-Ground Task Force-Crisis Response-Africa
SPMAGTF-CR-CC	Special Purpose Marine Air-Ground Task Force-Crisis Response-Central Command

TTPs	Tactics, Techniques, and Procedures
VEO	Violent Extremist Organizations
XML	Extensible Markup Language

EXECUTIVE SUMMARY

The September 11, 2012, attack in Benghazi, Libya, exposed a vulnerability in U.S. security and response capabilities. This immediately energized government efforts to rectify these deficiencies. In response, the Marine Corps established Special Purpose Marine Air Ground Task Forces (SPMAGTFs) Crisis Response elements. Marines deploy as part of these task forces in response to regional unrest around the world. One of the key tasks of these MAGTFs is to be able to conduct an embassy reinforcement if required.

In the modern security environment, the reduction of civilian casualties is paramount. Reducing civilian casualties is increasingly at the forefront of national defense policy and the rules of engagement (ROE) that forces are given in combat reflect this. Non-lethal weapons (NLWs) provide warfighters another tool in the continuum of force and can have tactical applications in the fixed site security of U.S. embassies. To explore the efficacy of using NLWs for this mission a scenario is developed using an agent-based model (ABM).

The scenario simulates a situation in which groups of local citizens have begun demonstrating outside the walls of a U.S. embassy. For this scenario, the embassy in Abuja, Nigeria is used. SPMAGTF elements have developed reinforcement plans for this location during real world deployments. The simulation play box for the scenario is shown in Figure 1.
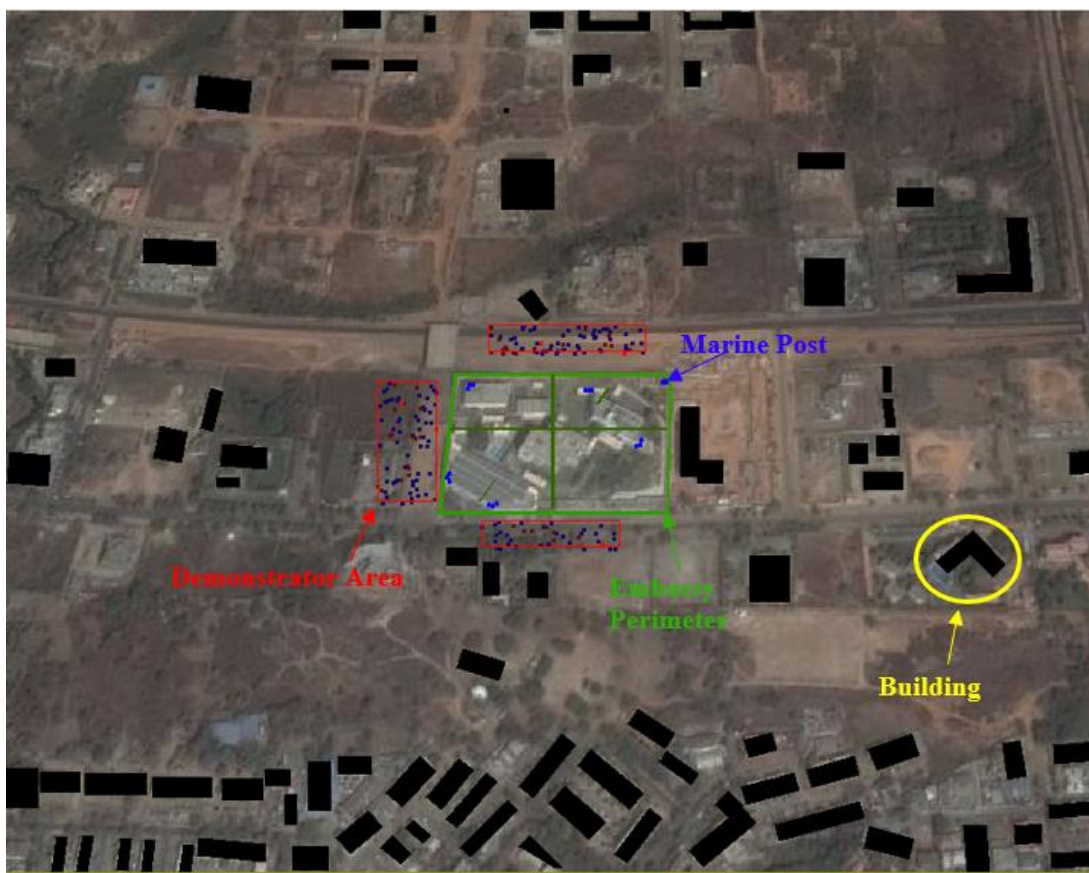
Figure 1. Scenario Play Box

The goal of the scenario is for the Marines to dissuade an escalation in violence from the crowd using the least amount of force possible. The NLW modeled is the XM1112 Airburst Non-Lethal Munition (ANLM), which is an airburst proximity flashbang grenade fired from an M203 grenade launcher. The goal of the research is to answer the following questions:

- Is the ANLM effective at reducing the lethality of the situation?

- Is there a tactical advantage gained by reducing the minimum engagement range of the weapon?

- Are there any tactical insights gained through using agent-based simulation?

In order to answer these questions a scenario is developed in the Pythagoras modeling environment. Pythagoras is the chosen modeling environment due to its ability

to account for the individual human elements of combat. Specifically, Pythagoras has the following attributes:

- Agents react individually based on changes in the environment.

- The ability to have different individual behaviors and actions within the same agent class.

- The use of behavior triggers to establish rules of engagement.

- The ability to increment allegiance of individual agents in a stochastic manner to better capture the intangibles of combat and peacekeeping operations.

Once the modeling environment is chosen, the next step towards answering the research questions is to determine an efficient design of experiments (DOE). The response variable and factors used in the experiments are shown in Table 1.

Response Variable		
Mean Number of Lethal Shots Fired		
Factor	Min Value	Max Value
Min Engagement Range for ANLM	15m	35m
Number of NLW systems per post	0	3
Starting number of red agents	1	20
Starting percentage of civilians that are blue-friendly	10%	90%

Table 1. Response Variables and Factors

The goal of the DOE is to establish a design that will efficiently explore the various combinations of factor levels in a manner that allows the experimenter to gain accurate insights into how the factors affect the response. Two methodologies are used to establish the design for this experiment. First, a nearly orthogonal Latin hypercube is used to establish design points for the following factors: minimum engagement range, number of red agents, and percentage of blue-friendly civilians. This results in 65 design points. This design is then crossed with the four factor levels for the number of NLWs

per post, giving a total of 260 design points for the experiment. Each design point was run 40 times, for a total of 10,400 simulated demonstrations.

The data output from the DOE is analyzed using multiple statistical analysis methods and visualization techniques. From these, the following results are found:

- The ANLM significantly reduces the number of lethal shots fired if it is included in the security force weapons load out.

- The minimum engagement range of the ANLM has little effect by itself in reducing the number of lethal shots fired.

- The number of NLW systems per post is the most influential factor; three NLWs dominate all other factor influences.

- The proportion of blue-friendly civilians in the local population heavily affects the aggression of the demonstration more so than the number of agitators present.

From these results, the following recommendations are made:

- If a minimum engagement range reduction is pursued for the ANLM, it must be reduced to less than 20 meters. Any reduction less than that would have minimal effect on the number of lethal shots fired and gives the warfighter little benefit over current capabilities.

- If intelligence indicates there is a likelihood of a strong contingent of agitators, arm each post with three ANLM-capable weapon systems. The mission can be sufficiently conducted with two ANLM-capable weapon systems; however, this comes with an increased risk to U.S. personnel.

- If less than 50% of the civilian population is friendly to U.S. forces, arm each post with three ANLM-capable weapon systems. The mission can be sufficiently conducted with two ANLM-capable weapon systems; however, this comes with an increased risk to U.S. personnel.

This research provides initial insights into the efficacy of NLWs and provides a baseline for further experimentation. Follow-on research topics include implementing ammunition restrictions, setting and varying additional triggers to explore different tactics and ROEs, including local force integration to allow for a defense in depth, varying the total population level, and adding dimensional aspects into the model, such as building access and terrain features.

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Lastly, and most notably, I would like to thank Mary McDonald, a research associate with the NPS SEED Center. You spent many hours working with me to build the model, design and run the experiment, and produce meaningful analysis. Without your time and support, I probably still would be swearing at my computer while trying to build agents in Pythagoras. Words cannot adequately express my gratitude for your assistance throughout this project; I sincerely appreciate it.

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I.   INTRODUCTION

The protection of civilians is fundamentally consistent with the effective, efficient, and decisive use of force in pursuit of U.S. national interests. Minimizing civilian casualties can further mission objectives; help maintain the support of partner governments and vulnerable populations, especially in the conduct of counterterrorism and counter-insurgency operations; and enhance the legitimacy and sustainability of U.S. operations critical to our national security.

—Executive Order 13732
U.S. Policy on Strike Measures to Address Civilian Casualties,
June 2016

A.   THE MODERN SECURITY ENVIRONMENT

The environment in which contemporary military operations take place is more complex than ever before. Modern military operations are no longer comprised of large force-on-force battles. Even when conventional warfare is expected and conducted, as in Iraq circa 2003, the battlefield devolves into a landscape that is much less black and white. It is not always clear who is an adversary and who is not. While an infantryman is still tasked with locating, closing with, and destroying the enemy, that alone is not enough.

In what senior military leaders coin the "new normal" security environment, modern forces must be able to conduct missions that cross the spectrum of warfare. Recently, the Commandant of the Marine Corps (CMC) wrote that this environment "yields new challenges, and demands varying, discriminating, and proportionate capabilities for our warfighters. From large-scale operations to smaller, more versatile distributed force response, everything we do must demonstrate our stewardship as global security leaders." (Neller, 2016, para. 2). With this guidance in mind, the applicability of non-lethal weapons (NLWs) is ever-changing on the modern battlefield. NLWs allow forces to have a larger range of responses and provide small-unit leaders more flexibility within their rules of engagement (ROE).

B.   NON-LETHAL WEAPONS: DEFINITION, POLICY, AND APPLICATION

When one hears the term "non-lethal weapon," usually what comes to mind is tear gas, a Taser, or a weapon that fires rubber bullets. While these are commonplace in law enforcement, they make up only a small portion of NLWs and capabilities. The Department of Defense (DOD) defines NLWs as

> weapons that are explicitly designed and primarily employed so as to incapacitate personnel or materiel while minimizing fatalities, permanent injury to personnel, and undesired damage to property and the environment… intended to have relatively reversible effects on personnel and materiel. (U.S. Marine Corps, 2003, p. I-1)

Within the DOD, the Joint Non-Lethal Weapons Directorate (JNLWD) handles the day-to-day operations of all NLW programs under the purview of the Executive Agent. The Executive Agent is always the CMC, by DOD directive. The DOD directive regarding NLWs is found in Appendix A. Figure 1 shows the DOD NLW program construct.
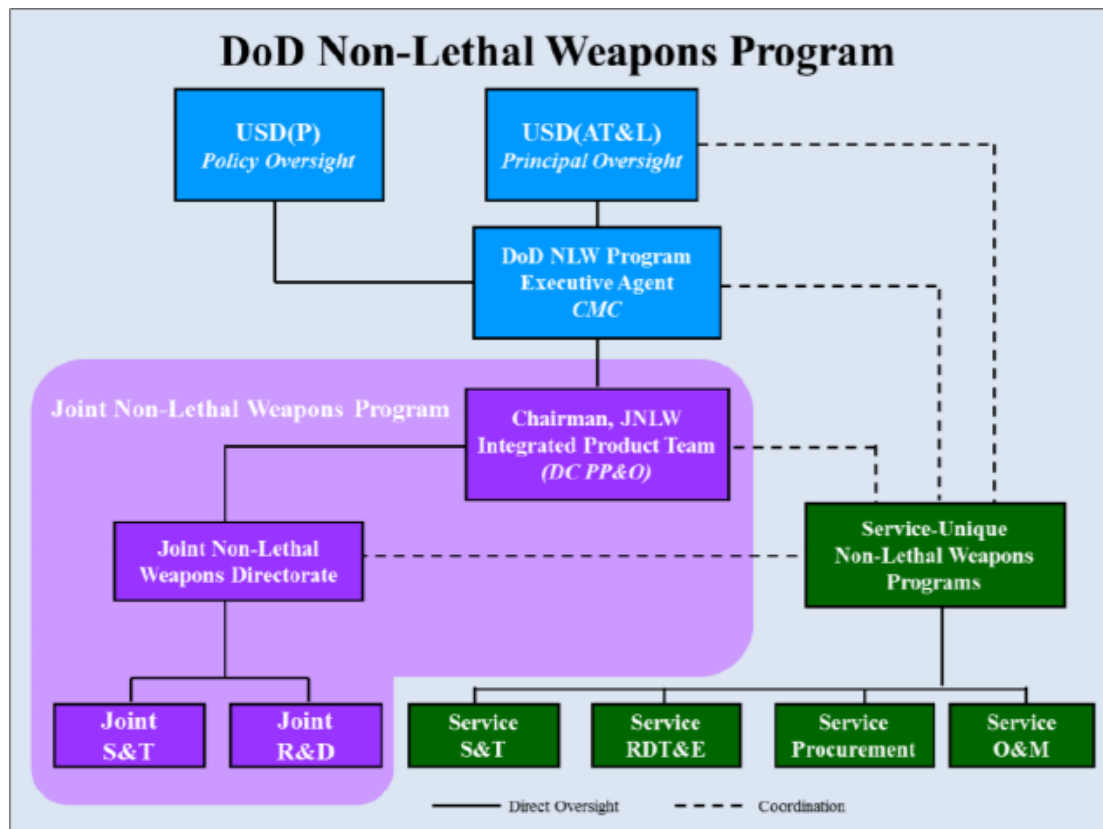
Figure 1.   DOD NLW Program Organizational Chart. Source: Neller (2016).

In the modern security environment, the reduction of civilian casualties is paramount. Reducing civilian casualties is increasingly at the forefront of national defense policy and the ROE that forces are given in combat reflect this. In July 2016, President Barack Obama issued an Executive Order to address civilian casualties in U.S. Operations. This order states that the United States will self-impose regulations that are more stringent than the international rules of armed conflict when it comes to the minimization of civilian casualties (Executive Order No. 13732, 2016). However, in this modern environment, it is often challenging to ascertain whether someone is a civilian or an enemy combatant. Whether fighting insurgents or Islamic State militants in Iraq or the Taliban in Afghanistan, it is inherently difficult to distinguish the enemy from an everyday civilian. Often, friendly forces cannot classify someone as a foe until they take fire from that person. This is a less than desirable method of identifying an enemy combatant.

The DOD recognizes the changes brought about by the modern operating environment, specifically, the increasing lack of tolerance for civilian casualties on the modern battlefield and the proliferation of this type of information though the media. The Marine Corps Warfighting Publication (MCWP) *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Non-Lethal Weapons* states that

> lethal firepower or the threat of its use may no longer be the default solution to all crises or problems. Senior leaders face a new level of public and media sensitivity and scrutiny concerning the proper role of the military as an instrument of national power. Field commanders must understand these sensitivities and attempt to achieve an appropriate military force. Junior leaders must apply the resulting decisions wisely, often in changing situations filled with uncertainty and danger (U.S. Marine Corps, 2003, p. I-1).

NLWs provide commanders flexibility and Marines in the field do not face the same extreme decision dilemma when only armed with conventional weapons. NLWs give warfighters more tools in the continuum of force and can be used to de-escalate a degrading tactical situation. For example, NLWs could have been used during a demonstration of approximately 200 civilians outside of Fallujah, Iraq, in 2004. Scott (2010) describes a crowd control issue in which demonstrators discharged AK-47s

recklessly near the rear of the crowd. A soldier fired a warning shot from his .50 caliber machine gun in response. This caused a gunner from another vehicle to open fire on the crowd, killing a number of civilians. Scott concludes that had the soldiers been equipped with NLWs, the result could have been avoided.

With only conventional weapons, a Marine could be forced into making an extreme decision. He can shout a warning and hope that tone, words, and body language are enough to dissuade a potential adversary, but if this is not effective, a Marine can become part of a dangerous waiting game, putting his and his comrades' lives at risk. The other option, firing first, means risking the safety of civilians who may not understand warnings. Neither of these options seems ideal, which is why the DOD seeks to address this vulnerability through the use of NLWs.

The DOD categorizes NLWs by their basic purpose, either counter-personnel or counter-materiel. Counter-materiel NLWs are used to stop, disable, or divert vehicles, vessels, or aircraft. The effects of counter-personnel NLWs cover a wide spectrum, including vision degradation through laser dazzlers, mobility degradation/dissuasion through directed energy, disabling individuals through low velocity kinetic rounds, and suppressing/disabling individuals with an area effect weapon such as a flashbang or gas grenade (Joint Non-Lethal Weapons Directorate, 2016b). This research focuses on the use of a counter-personnel NLW in a fixed site security scenario.

C.   THE MARINE CORPS SPECIAL PURPOSE MARINE AIR-GROUND TASK FORCE

1.   Background

Many regions of the world in which the DOD operates are large territories characterized by government instability, chaotic environments, and volatile local populations. In order to respond to threats in these dynamic environments, the Marine Corps established two standing Special Purpose Marine Air Ground Task Forces (SPMAGTFs) in 2014. The two units, SPMAGTF Crisis Response Central Command (SPMAGTF-CR-CC) and SPMAGTF Crisis Response Africa (SPMAGTF-CR-AF), are

task organized and trained for missions that may rapidly emerge throughout these regions.

2. Embassy Reinforcement Missions

The attacks on the U.S. embassy in Benghazi, Libya, in 2012 made a crisis response force of utmost importance to U.S. national security interests. The ability to conduct a rapid embassy reinforcement is one capability the crisis response SPMAGTFs give component commanders. All SPMAGTF staffs plan and train for an embassy reinforcement scenario. As part of the training for this mission, Marines train with both lethal and non-lethal weapons. In order to use this capability, the Department of State (DoS) must request the force from the component commander whose area of operations (AO) the embassy falls within.

The Marine Corps has exercised this reinforcement capability in both Baghdad, Iraq and Sana'a, Yemen. In both of these instances, Marines from the supporting unit worked with the DoS and the Marine Corps Embassy Security Group (MCESG) detachment to provide fixed site security for the embassy. Despite training with NLWs, the Sana'a reinforcement force focused almost solely on lethal means of security once at the embassy. However, NLWs can aid in the ground force commander's awareness of local intent without escalating immediately to lethal means, which may not be necessary in certain scenarios. This capability may prove valuable when guarding sovereign territory in another country, specifically when that territory is surrounded by local civilian populations.

D. OBJECTIVE

With one of the primary mission sets for the SPMAGTFs being embassy reinforcement, a study is required to determine if NLWs may produce a tactical capability that would be advantageous for a unit conducting this mission to have. This research aims to study the efficacy of modeling and simulation in determining the effectiveness and tactical use of NLWs for fixed site security in a semi-permissive environment. Simulation is used due to the fact that "it enables researchers to construct and study valid models of complex systems in relatively simple and straightforward ways" (Lucas et al., 2015, p.

293). This decision is expanded upon in subsequent chapters. As technology continues to improve, it is important to examine new or emerging weapons that may bring more advanced and effective capabilities to the tactical and strategic arsenal. With this in mind, this research also aims to determine what effects emerging NLWs must be able to produce in comparison to already existing capabilities. This is critical to ensuring resources are expended appropriately in a fiscally constrained environment.

E.   SCOPE OF THESIS AND RESEARCH QUESTIONS

To best develop tactics, techniques, and procedures (TTPs) for the employment of NLWs, this research first chooses a weapon system currently near the end of the DOD acquisition pipeline and develops a semi-permissive scenario in which its employment is as realistic as possible. With the given weapon system and scenario, an agent-based simulation is utilized to determine the best TTPs for the employment of the specific weapon system in the chosen environment. Additionally, weapon specifications are explored in order to assist in the development or procurement of the NLW.

F.   METHODOLOGY

To conduct this research, a process known as data farming is used. Data farming is defined as

> a method to address decision-maker's questions that applies high performance computing to modeling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options. (Project Albert, 2006, para. 1).

This entails efficiently running over 10,000 separate experiments, collecting hundreds of thousands of data points, processing and analyzing this data, identifying significant factors and interactions, and classifying significant performance thresholds (Sickinger, 2006).

II.   SCENARIO DEVELOPMENT

> Our current operating environment remains volatile and complex, so the demand for our unique service capabilities continues to grow. Indications are that the future will remain as challenging and uncertain.
>
> —Force Development Strategic Plan
> Marine Corps Combat Development Command, October 2016

A.   SCENARIO LOCATION AND OPERATIONAL PICTURE

The scenario in which this research is undertaken is modeled as semi-permissive, also referred to as an uncertain environment. Joint Publication 3–35, *Deployment and Redeployment Operations*, describes an uncertain operating environment as one in which "host nation forces do not have totally effective control of the territory and population" (Department of Defense, 2013, p. I-2). With situational uncertainty on the ground, the variability in possible operational results is wide. In this environment, the commander on the ground cannot know the likelihood of operations devolving into full hostility; this is the situation in which non-lethal weapons can have the largest impact on operational outcomes.

The idea behind having Marines reinforce a United States embassy is to ensure the safety of U.S. citizens and sovereign property on foreign soil. While the added presence of U.S. combat troops can lead to a reduction in the aggression of a local populace, there is some probability that the opposite effect may occur. An increasingly visible region of the world with precarious security situations is Africa. The overall security concern is best summed up in the U.S. Africa Command (AFRICOM) 2017 posture statement:

> Parts of Africa remain a battleground between ideologies, interests, and values: equality, prosperity, and peace are often pitted against extremism, oppression, and conflict. The strategic environment includes instability that allows violent extremist organizations to grow and recruit from disenfranchised populations. Currently, the greatest threat to U.S. interests emanating from Africa is violent extremist organizations (VEOs)…They build partnerships with regional VEOs; exploit the vulnerability of Africa's youth population; and take advantage of ungoverned and under-governed spaces to target our partners, our allies, and the United States.

Africa's population faces large scale unemployment and disenfranchisement from corrupt governments and abusive security forces, making them prime targets for exploitation by criminal and terrorist organizations across the continent. (U.S. Africa Command, 2017, p. 3)

The U.S. embassy in Abuja, Nigeria, was chosen as the location for this scenario. Nigeria has been plagued with instability and a deteriorating security climate. This, combined with the country's vast resources, make it of key concern to U.S. national security interests. Boko Haram, a VEO based out of Nigeria, has been of particular concern in recent years. The group made world headlines with the kidnapping of more than 200 young girls in 2014 and with a public declaration of loyalty to the Islamic State of Iraq and Syria (ISIS) in 2015. Boko Haram has also conducted a number of attacks throughout Nigeria, including a bombing of the UN headquarters building in Abuja in 2011 (Mshelizza, 2011). Figure 2 shows a map of Nigeria, and Figure 3 shows a density map of all Boko Haram attacks from July 2009 to January 2015.

Figure 2. Map of Nigeria. Source: Central Intelligence Agency (2017).

Boko Haram fatal attacks
Civilians reported killed in Boko Haram attacks Jul 2009 - Jan 2015
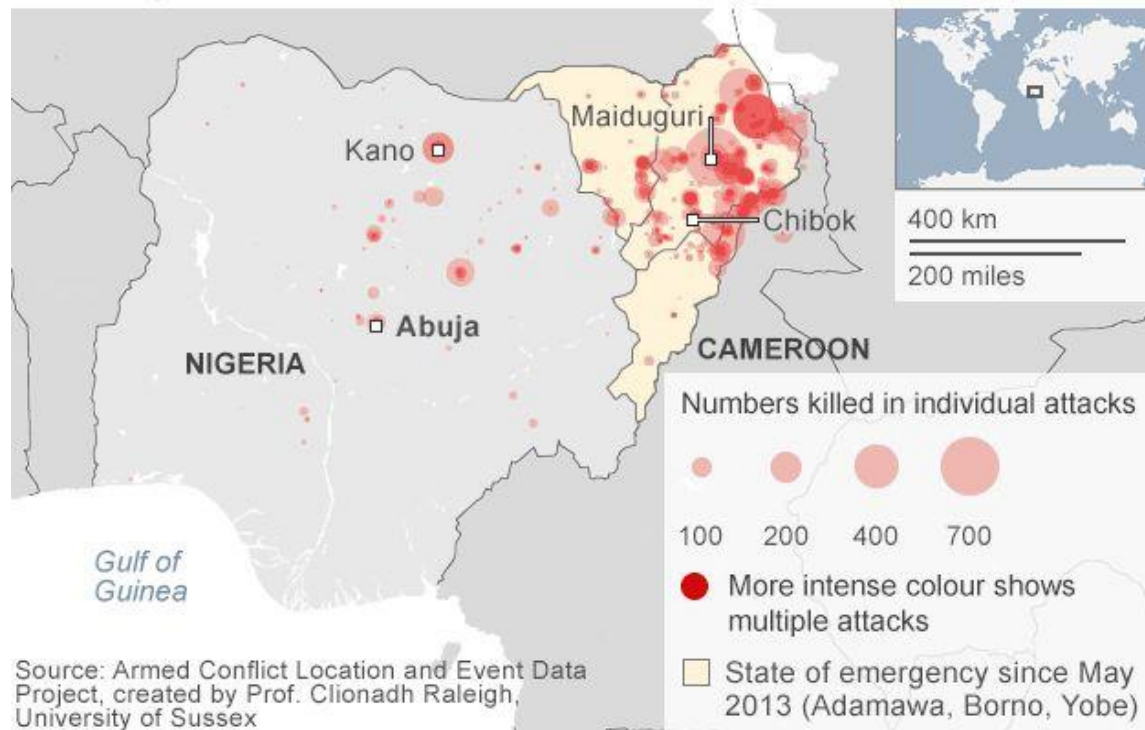
Figure 3. Density Map of Boko Haram Attacks. Source: Ross (2015).

On March 9, 2017, General Thomas Waldhauser, commander of AFRICOM, testified before the Senate Armed Services Committee. As part of his opening statement, he said, "In West Africa, our primary focus is containing and degrading Boko Haram and ISIS-West Africa… we are working to enable regional cooperation and expand partner capacity to ensure Boko Haram and ISIS-West Africa do not further destabilize the region" (Waldhauser, 2017, p. 2). Nigeria is within SPMAGTF-CR-AF's area of operations (AO), and is therefore carefully monitored with plans in place for different contingencies, including embassy reinforcement, if requested by the ambassador.

The scenario is designed to take place after the local ambassador has requested an embassy reinforcement force and the SPMAGTF deploys a platoon in support of this mission. The platoon will land in a predetermined location and conduct a dismounted patrol to the embassy. The patrol portion is modeled in a separate thesis. The simulation for this thesis takes place after the conclusion of the patrol and after the platoon establishes six

security positions around the embassy's perimeter. These positions were identified with the tactical input of Major Jeremy Colwell, who was the security force commander in Sana'a, Yemen in 2013. These security positions are based purely on open source satellite imagery and may not be the most tactically advantageous positions in reality. The embassy perimeter along with the security post positions are shown in Figure 4.
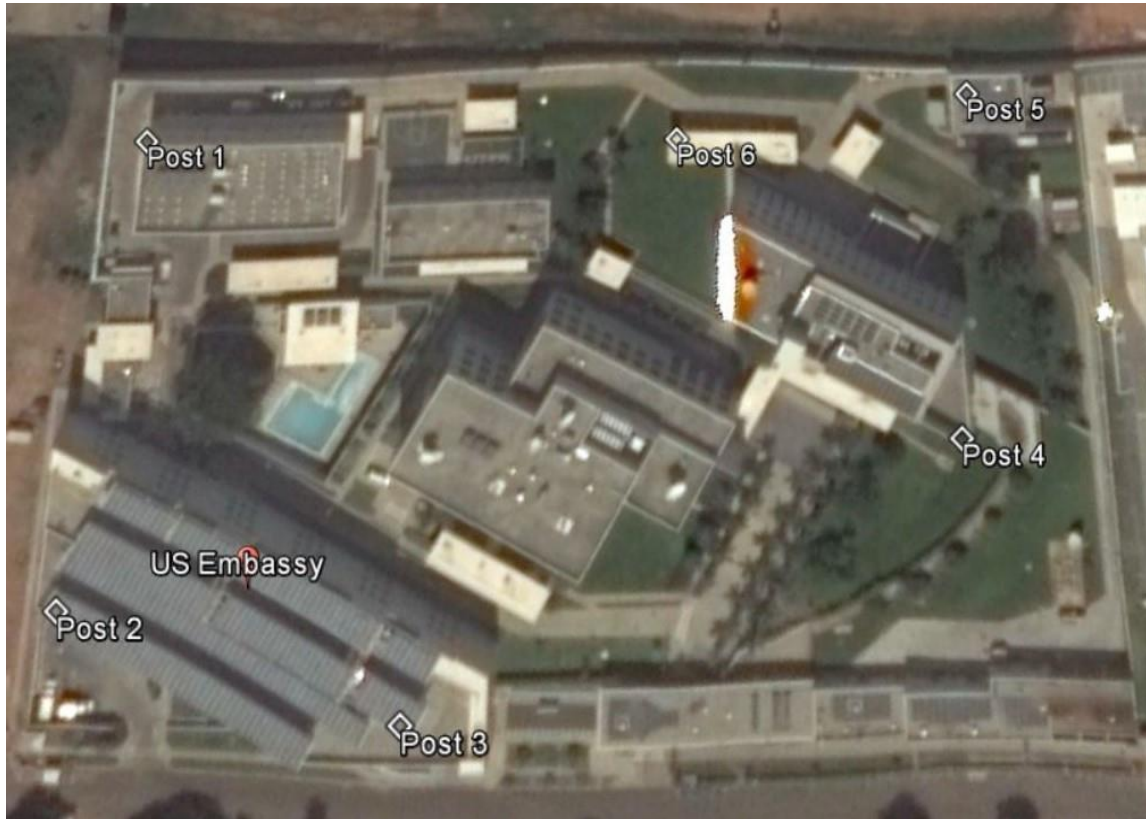
Figure 4. U.S. Embassy in Abuja with Security Posts Marked. Adapted from
Google Earth (2017).

In this scenario, there are groups of local civilians around the embassy. These civilians are in the beginnings of a protest or demonstration. The idea behind this simulation is for the Marines to interact with the local populace from their posts, with the goal being to quell crowd unrest and avoid escalating to lethal means. The specifics of the scenario are discussed in detail later.

B. NON-LETHAL WEAPON SELECTION

In the chosen scenario, the reinforcement platoon is equipped with only personal weapons. If these weapons possess only lethal capabilities, there is no alternative for escalation of force between voice commands and lethal rounds. With the issue of crowd unrest, an area fire weapon that disperses non-lethal effects could provide a method of force escalation that may prevent the unnecessary loss of life. The idea behind this reduction in lethality is that the NLW could persuade civilians to either clear the area or become friendlier towards U.S. forces. However, as with the use of any type of force, the NLW may have the opposite of the desired effect. In order to explore this effect, an appropriate NLW has to be selected for modeling.

The XM1112 Airburst Non-Lethal Munition (ANLM) is a new NLW currently in the DOD acquisition pipeline. It is scheduled for fielding in the second quarter of fiscal year 2018. The ANLM is a low-velocity 40-millimeter (mm) flashbang grenade. It comes with two firing methods, delay and proximity. The delay mode allows the weapon to be used in an urban environment and fired into an opening such as a window. The proximity mode causes the round to detonate approximately five meters from the target. This allows for a consistent non-lethal effect regardless of target range. For the purposes of this study, only the proximity firing mode is modeled. The specifications of the ANLM are shown in Table 1 (Joint Non-Lethal Weapons Directorate, 2016a).

Table 1.   XM1112 ANLM Specifications

Min Range	35 m (required threshold)/15 m (operational desire)
Max Range	300 meters
Firing Rate	5-7 rounds/min
Blast Radius	5 m
NL Effects	≥ 30 secs (threshold)/ ≥ 60 secs (desire)

The ANLM can be fired from the M203 or newer M302 grenade launcher. Since the Marine Corps is not fielding the M302, only the M203 will be referred to henceforth.

The M203 is a modular attachment that mounts to the underside of the M16 or M4 service rifle. Figure 5 shows the M203 mounted on an M4 carbine and Figure 6 shows the ANLM.

Figure 5. M203 Mounted Under M4 Carbine. Source: Modern Firearms (2017).

(K. Swenson, personal communication, December 29, 2016).

Figure 6. XM1112 ANLM.

Since the M203 is an attachment, the ANLM does not actually require Marines to be burdened with a completely separate weapon system to carry, only additional ammunition. With the M203 being attached to the lethal weapons system, Marines are not forced to switch weapons to achieve non-lethal effects. Additionally, the ANLM covers a tactical space that most other NLWs cannot reach. This, combined with the ease of use and small impact on the Marine's individual load, makes the ANLM a particularly

enticing option for this type of mission. Figure 7 depicts the tactical reach of the ANLM in comparison to other NLW systems.
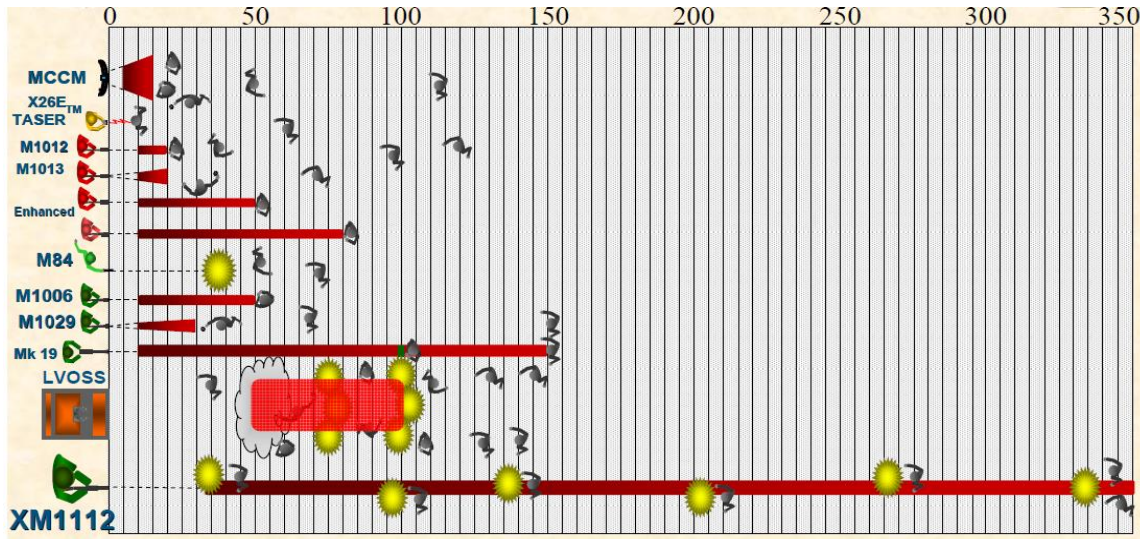
The x-axis represents distance in meters. The red bars indicate the coverage of each different weapon system shown on the y-axis. The ANLM is depicted at the bottom of the graph.

Figure 7.   ANLM Tactical Coverage. Source: Armament Research, Development, and Engineering Center (2007).

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III. MODELING AND SIMULATION

A model is useful if a better decision is made with the information it adds.

—Captain Wayne Hughes, USN (Ret)
Naval Postgraduate School

A. DEFINITION AND APPLICATION

The DOD defines a model as "a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process" (Department of Defense, 2009, p. 10). A system is defined as a set of objects or elements that interact with one another in some way (Sanchez, 2007). In this study, the system is comprised of people and weapons. There are numerous types of models. For the remainder of this thesis, "model" will refer specifically to a computer model. There are numerous benefits to using models. For example, models can be used to study system behaviors and attributes prior to the physical system being created; to analyze a system that would not otherwise be possible; or to explore and mitigate risk. A large force-on-force battle or the use of a flight simulator to practice emergency procedures are good illustrations of these uses. For a model to be beneficial, a user must have some method of implementation.

A simulation is simply a "method for implementing a model over time" (Department of Defense, 2009, p. 10). The purpose of a simulation in conducting analysis is "to mimic behavior to understand or improve system performance" (Nance & Sargent, 2002, p. 161). Figure 8 shows the general methodology behind using simulation for analysis. Modeling and simulation (M&S) are powerful tools with their use becoming more common with continued proliferation of new technologies (Lucas et al., 2015). Simulation allows users to take intricate systems and conduct experiments to gain insights. This is particularly useful in the DOD, where live testing of a system can be extremely expensive. Firing a live rocket may cost upwards of $1 million dollars per shot depending on the weapon system. While live testing is always preferred, it is not always reasonable or even possible. For instance, it may not be reasonable to shoot 100 expensive rockets in order to

study the possible effects they bring to bear on a fortified position. While establishing a model and simulation does incur some cost, it is nowhere near as expensive as live testing in many cases. Additionally, simulating one missile shot versus simulating 100,000 shots bears virtually no difference in price thanks to the availability of modern era computing power. The DOD Modeling and Simulation Coordination Office (DMSCO) homepage states "Modeling and simulation is an enabler of warfighting capabilities. It helps to save lives, to save taxpayer dollars, and to improve operational readiness…M&S helps provide a safer and lower resource-intensive rehearsal capability" (2017).
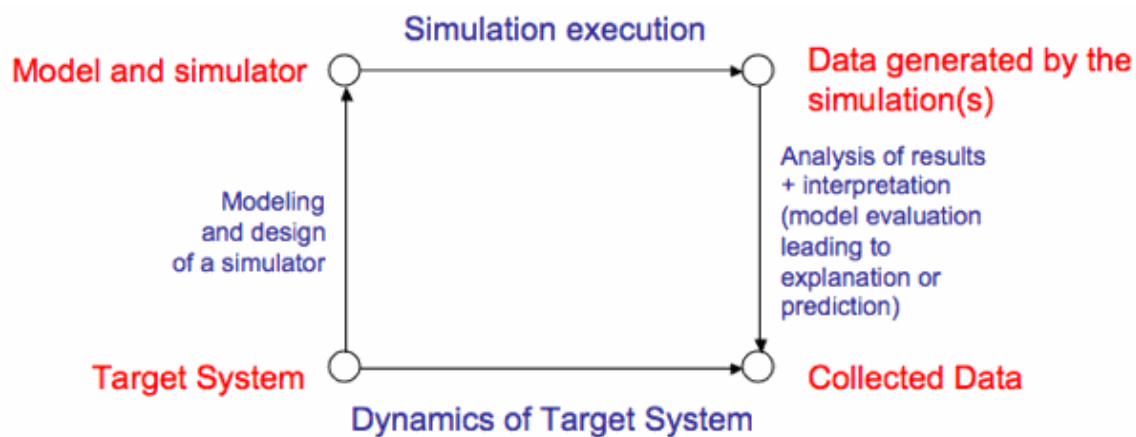
Figure 8. General Schema for Analysis Using Simulation.
Source: Bandini et al. (2009).

B.   CHOOSING A SIMULATION METHOD

There are numerous types of simulations used throughout the DOD. To determine the best method of simulation, one must first define what needs to be modeled. Table 2 defines the attributes needed for this model. From this table a common connection can be seen between all entities in the system. They all must interact with one another and change their behavior based on environmental changes. These traits fall in line with the features Dr. Charles Macal uses to identify whether a problem is a good candidate for agent-based simulation (ABS). In this list of features, Macal includes the following traits that fall in line with this model's requirements: when it is important that agents cooperate or form organizations, when it is important that agents move over a landscape, when

agent relationships form and dissipate, and when the goal is to model individual behaviors in a diverse population (Siebers et al., 2010). The overarching idea behind ABS is to "represent the behavior of entities which are active in the world, and that it is thus possible to represent an emergent collective behavior that results from the interactions of an assembly of autonomous agents" (Cioppa et al., 2004, p. 172). Based on this definition, the features described by Dr. Macal, and the requirements listed in Table 2, ABS is an appropriate method to use for this simulation.

Table 2.   Desired Model Attributes

People	Behavior	Weapons Possessed
Marines (Blue)	Adherence to ROE, influenced by behavior of civilian agents	Voice, M-4, ANLM
Civilians (Blue Friendly)	Autonomous, possess different levels of friendliness, influenced by changes in the environment, influenced by blue and red commands	Rock (instigation method)
Civilians (Red Friendly)	Autonomous, possess different levels of "agitation," influenced by changes in the environment, influenced by blue and red commands	Rock (instigation method)
Antagonists (Red)	Autonomous, possess different levels of "agitation," influenced by changes in the environment, influenced by blue and red commands	Voice, Rock, AK-47
Weapons	**Desire**	**Effects**
Voice Command	Deter or instigate those "hit" by voice	Influence friendliness or agitation, stop, move away, instigate, attack
Lethal Weapon	Produce lethal effects on target	Has probability of kill, probability of hit, results in agent "death"
NLW	Incapacitate a group of agents,	Has probability of kill, probability of hit, results in agent incapacitation with certain probability
Rock	Instigate blue agents into a reaction	Causes Blue force to escalate force after a certain number instigating shots
Terrain	**Design**	
Buildings	Provide cover and concealment, no agents enter, obstruct sight	
Walls	Contain sector of fires for blue agents in embassy	
Vegetation / Open	Freedom of movement and clear line of sight	

C. SELECTING THE MODELING ENVIRONMENT

Once a simulation method is determined, an environment to implement the simulation must be chosen. An environment is simply a computer program to run the simulation. After discussing the traits of the model, two environments came out as candidates for this simulation: Map Aware Non-Uniform Automata (MANA) and Pythagoras.

1. MANA

MANA is an agent-based, time-stepped, stochastic, mission-level environment developed by the New Zealand Defence Technology Agency (McIntosh et al., 2007). The goal of this environment is to create a scenario that captures the physical and behavioral aspects of a situation, but does not include unnecessary detail. This allows users to quickly explore multiple possible outcomes. MANA has some key features that make it an attractive modeling environment for the embassy security scenario:

- Agents are aware of their environment through organic sensing capability or through communication with other agents. They also retain memories.

- Each agent type has its own unique set of properties.

- Agents react individually based on changes in the environment.

- Users are able to set triggers (i.e., being shot at, being hit with non-lethal munition) to change agent behavior.

- Agents can have multiple weapons with specified targeting priorities (McIntosh et al., 2007).

However, one key constraint of MANA is that within an agent class, all behavioral characteristics are shared. If an individual is classified as a blue-friendly agent, his behaviors will be shared by all other blue-friendly agents. There is no ability for any individuality to be built into an agent class, which is problematic. For instance, if two blue-friendly agents are hit with a flashbang munition they will react the same way in the simulation, when in reality one person may have a completely different reaction than the other. One may get angry and become more antagonistic while the other may completely evacuate the area. In order to achieve this individual behavior effect in

MANA each individual agent will have to be its own class with different behaviors defined for each, which is not a realistic modeling approach.

2.   Pythagoras

Pythagoras is an agent-based modeling (ABM) environment designed by Northrop-Grumman under a contract from the Marine Corps. Pythagoras shares many traits with MANA, including the ability to set triggers, targeting priorities, and individual reactions to environmental changes. The Marine Corps issued the contract in order to develop a tool that more realistically models the intangibles of combat. Figure 9 illustrates the characteristics of a combat environment, both tangible and not. In discussing the concept behind the construction of Pythagoras, the user's manual states:

> Traditional combat modeling and simulation have concentrated on the physical aspects of combat. Rates of movement, rates of fire, lethality, the effect of weather, terrain, etc., are all phenomena that are measurable to some degree and lend themselves to mathematical representations. However, the combat environment involves not only the physical world, but also human factors (features that motivate soldiers or deter them from engaging in combat) and leadership (the ability to inspire, integrate, and employ soldiers and weapons to attain an objective) (Northrop Grumman, 2008, p. 1).
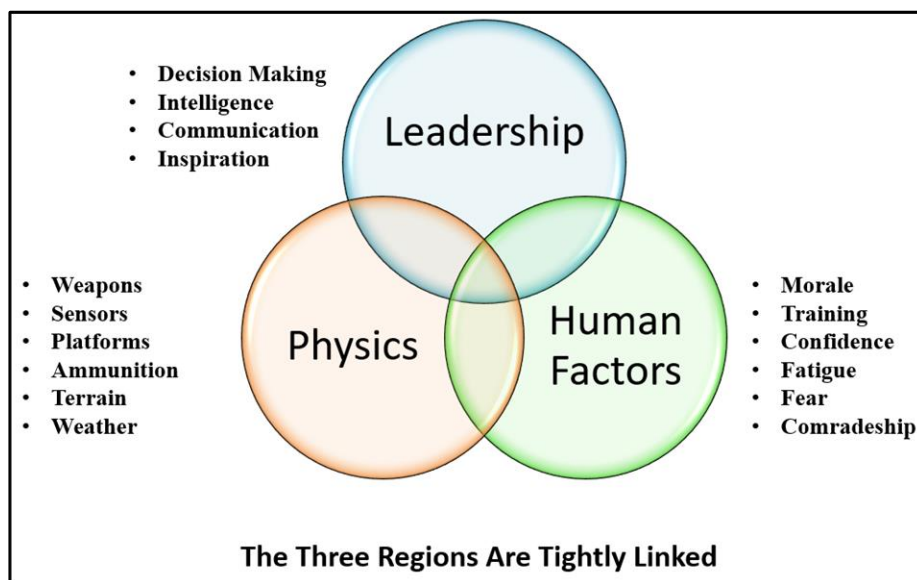
Figure 9.   Features of a Combat Environment (Northrop Grumman, 2008, p. 1).

To account for the individual human elements of combat, Pythagoras implements fuzzy logic. Fuzzy logic allows for what are typically binary variables to be placed on a continuous spectrum. For example, an agent does not have to be classified as purely an enemy (1) or not (0). With fuzzy logic, an agent may hold a value of .8, indicating he is ideologically or behaviorally close to an enemy. This fuzzy logic allows for the implementation of what the user's manual calls "soft rules." Soft rules allow users to "fix agent desires and thresholds for a specific replicate, but allows the agent's desires and thresholds to be varied from replicate to replicate, and to be varied from agent to agent within a replicate" (Northrop Grumman, 2008, p. 2–2). The ability to vary individual agent desires and reactions, even within the same agent class, allows for a model that more closely replicates real human behavior. In reality, every individual has personal motivations and internal drive. Pythagoras allows for an agent class to have a range of individual decision thresholds by utilizing random number draws for each agent's individual threshold. Figure 10 illustrates the idea of individuality within an agent class.
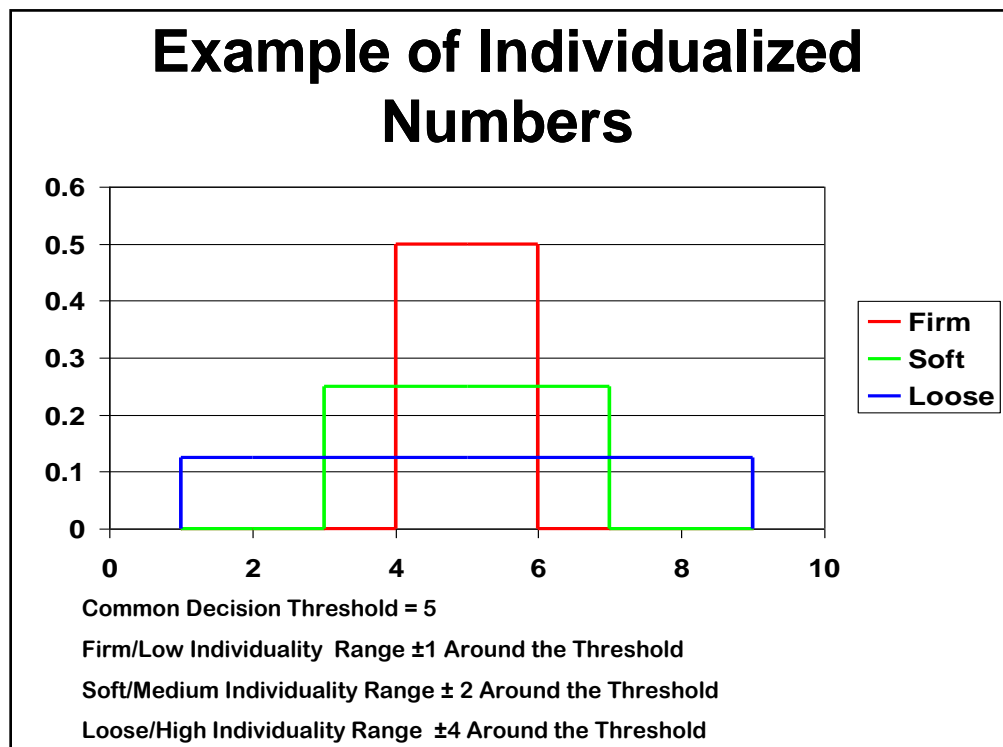
Figure 10. Example of Degrees of Individuality for Individual Agents. Source: Northrop Grumman (2008).

A decision threshold is the point an individual reaches that elicits some sort of action. The common decision threshold in Figure 10 is set at five. In this case, let us say that represents the decision for a civilian to shoot at a Marine. The red line represents an agent class that is more ideologically inflexible. The individual agents in this class will each have a decision threshold between four and six. That is, they do not vary too far off the common threshold point. This could be representative of groups like hard-line jihadists and other extremists. The green line represents an agent class with more variability in their reaction thresholds. This could represent civilians who are not necessarily sympathetic to the U.S. cause, but are not outright aggressors. The blue line represents an agent class with widely varying individual tendencies. It is basically a crapshoot on what the agents in this class do. The ability to model differing individual human behaviors within the same agent class makes Pythagoras the ideal environment to model the embassy security scenario.

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IV.   BUILDING THE MODEL

War is intrinsically unpredictable. At best, we can hope to determine possibilities and probabilities.

—Marine Corps Doctrinal Publication 1: Warfighting
June 20, 1997

Pythagoras is written in and runs using Java and uses extensible markup language (XML) to store the simulation's inputs into a single scenario file; however, it comes with a graphical user interface (GUI) that makes it relatively easy for users to construct the model. A screenshot of the GUI before any portion of the model is constructed is shown in Figure 11.
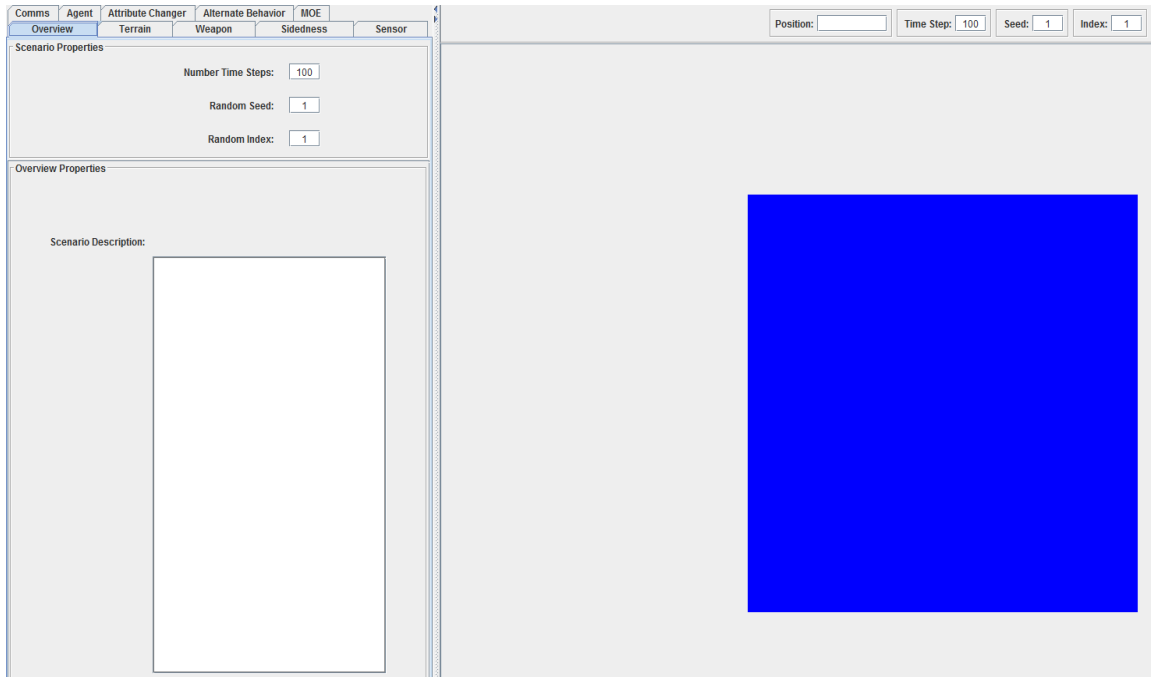
Model components are developed via the tabs at the top left. The blue screen is the play box. This is where the agents are placed and interact with one another.

Figure 11. Pythagoras GUI Home Screen.

The tabs in the upper left of the GUI are used to build each component of the model. With the exception of the communications component, all other components are used in the construction of this model. The components used are as follows:

- Overview

- Terrain

- Weapon

- Sidedness

- Sensor

- Attribute Changer

- Alternate Behavior

- Agent

- Measures of Effectiveness (MOEs)

A.   MODEL ASSUMPTIONS

Combat is an inherently complex endeavor. Thus, modeling a combat scenario is an inherently complex undertaking. Trying to model every intricacy can lead to pitfalls, as "the more one tries to imitate reality, the more uncertainty is introduced into the model" (Wittwer, 2006, p. 44). Assumptions must be made to generalize certain complexities and to make the model structured in a way that results are meaningful. Key assumptions made to construct this model are outlined below.

1.   Perfect Lethality

When a red agent fires an AK-47, he is perfectly accurate and a single shot always kills a blue agent. The same holds true for blue agents firing the M4. This assumption has two purposes, the first of which is to create a trigger for blue agent ROE. When a blue agent is killed, all other blue agents know to use lethal force. The second purpose is for lethality tracking. By ensuring that a single lethal round has a lethal effect, it creates an even baseline for each simulation run. There is no variability due to inaccuracy or the chance of a lethal round not having lethal effects.

2. Perfect Non-Lethal Effects

In order to determine whether the ANLM reduces lethality, the effects of the ANLM are modeled as perfect. That is, it meets all specifications put forth in the technical specifications. The ANLM is a weapon still in the acquisition pipeline, as such there is no real-world data for its usage. Additionally, non-lethal weapons may have differing effects on different people in various situations. Keeping the effects constant allow for a baseline in the model.

3. Permanent Lethal State

Once an agent goes lethal, there is no de-escalation. If a blue agent fires an M4, he will no longer be willing to fire a NLW or use voice commands. In similar fashion, if a red agent fires an AK-47, he will not be willing to curb his lethality or aggression. While this may not be 100% realistic, attempting to simulate individual human decision making requires a level of intricacy that is not the focus of this thesis. Additionally, we wanted to model a worst-case scenario for the escalation of lethality.

B. OVERVIEW

The overview tab in the GUI simply allows the user to set the random seed value, random index value, and number of time steps for the simulation to run. The random seed sets the initial conditions for the simulation, the random index generates all the random draws for the simulation run, and the time steps dictate how long the simulation runs for. There are no stopping conditions for this simulation, each one runs for a fixed duration of 250 time steps. This scenario occurs during the small window of time at which a demonstration reaches a tipping point and the situation becomes tenuous for the Marines on post; therefore, each time step represents roughly one second. This is long enough for all agents to interact with one another and for the scenario to develop sufficiently far enough to draw conclusions from.

C. TERRAIN

Pythagoras uses a play box to represent the physical space in which the simulation takes place. To develop the play box, an image of the AO was imported to Pythagoras.

This image is shown in Figure 12. While the image does not have any attributes itself in the play box, it allows for users to get a more realistic visualization of agents' movements and interactions. The embassy compound is in the center of the image; the dimension of the total AO is 1283×993 meters. Distance in Pythagoras is measured in computer pixels, with each pixel on the play box equating to 1.5 meters for this scenario.

Figure 12. AO Image Imported into the Play Box.

The AO has multiple roads, buildings, and open space throughout it. Pythagoras allows for different physical features to be added into the model, with each feature having its own set of characteristics. The baseline feature that all scenarios start with is open space. This means agents can move freely, but with no concealment or protection. There is a sub-menu within the terrain tab that allows for additional features to be added to the play box. This menu is shown in Figure 13.
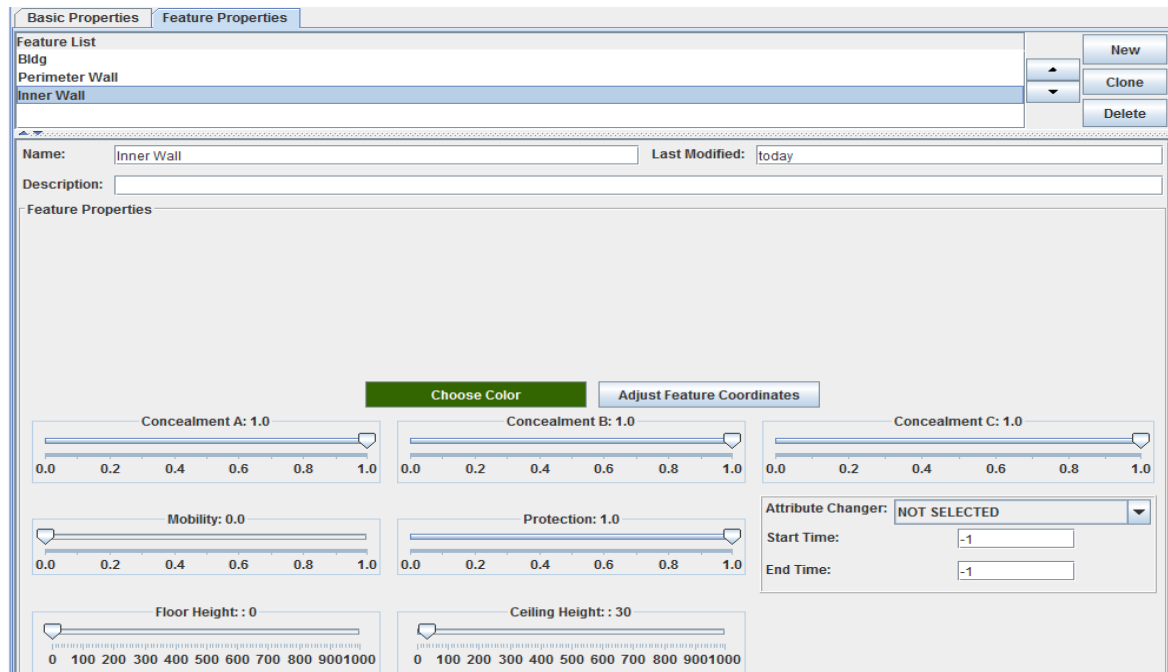
Figure 13. Pythagoras Terrain Physical Features Menu.

In order to prevent agents from moving through inaccessible areas, features have to be added into the play box. Polygons are individually drawn on top of each building on the AO image, with the mobility parameter set to zero in order to prevent agents from walking through the buildings. The perimeter wall to the embassy is set in the same way, with mobility, concealment, and protection set to zero. This prevents the Marine agents from leaving the embassy compound and civilian agents from entering, but allows all classes of agents to see each other and if necessary, fire onto each other. Additional inner walls are built into the embassy, with concealment and protection parameters set the maximum level and ceiling height set to 30 pixels. This prevents any weapons from being fired through the walls and keeps Marines shooting within their sectors of fire. The final play box with all features and agents added is shown in Figure 14. The black polygons are buildings, the light green rectangle is the embassy perimeter, and the dark green lines are the perimeter walls. The red rectangles delineate the starting area for three groups of civilians and do not represent any physical features.

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Figure 14. Final Scenario Play Box.

D.   WEAPONS

There are two types of weapons in Pythagoras, classic weapons that inflict damage to other agents and weapons of influence. The ability to use weapons to model agent influence is a key component to this simulation. These weapons allow for the transmission of intangible traits between agents. For example, an enemy agent firing a voice weapon may influence a neutral civilian to be more aggressive. In some cases, the weapons have both physical effects and influence effects. In this scenario, the ANLM produces the non-lethal effects associated with it and also influences the "sidedness" of individual agents. How influential the ANLM is at deterring an escalation in violence from the crowd is the overarching question the model looks to answer. Table 3 shows a breakdown of all weapons modeled for this scenario, there are no ammunition constraints for any of these weapons.

Table 3.   Weapons Used in the Model

Loud Speaker	Red, Blue	All Civilian Agents	Shoots "color" in order to influence civilian population.
Rock	All Civilians, Red	Blue Agents	Representative of any method of non-lethal provocation towards blue forces. Enough provocation will cause blue to employ a NLW.
AK-47	Red-Friendly Civilians, Red	Blue Agents	Kills a blue agent when shot.
M-4	Blue	Red Agents	Kills a red agent when shot.
ANLM	Blue	Civilian & Red Agents	Will cause any agent within 5 meters if blast to be stunned for 30 seconds. Also will cause a random shift in "sidedness" of any civilian agent hit.

E.   SIDEDNESS

Pythagoras uses color association to establish association between agents within the simulation. There are three color choices: blue, red, and green. In this scenario, blue represents friendly forces (Marines), red represents enemy forces (aggressors/instigators), and green represents completely neutral civilians. The terms "blueness" and "redness" are used to describe the level of affiliation an agent has with each side. Each color exists on a scale of 0 to 255. In describing how agent affiliation is determined by color, the Pythagoras user's manual states the following:

> Agents with similar color (as measured by either the difference in absolute value or the root sum square of the differences of the active colors) are considered to be members of the same unit. Those whose color is close are considered to be friends. Those whose color is far away are considered to be enemies. Colors between enemy and friendly agents are neutrals. That approach allows for multiple affiliations within a single scenario, as might be found in a crowd (Northrop Grumman, 2008, p. 9–1).

The color of each agent is established at the start of every simulation run based on starting values established by the user. With the starting values is also a predefined tolerance set by the user. This is a soft rule implementation that allows for a spectrum of sidedness for every agent. For instance, red-friendly civilian agents have a starting red value and blue value of 100 and 20, respectively. Each of these have a tolerance of 20. This allows for each agent to start with a different level of redness and blueness every run. The color of an agent is influenced by events in the simulation and the color also allows for behavioral triggers to be built within the agent. This allows agents to essentially change sides during the course of a simulation and behave accordingly. For

example, a blue-friendly civilian may be getting hit repeatedly with the red loudspeaker weapon, causing their redness to increase. If they get hit with a NLW, that may push their redness or decrease their blueness to a level where they become red-friendly civilian agents. If their redness reaches a certain level, they may now be willing to use the rock weapon to antagonize blue forces.

F.   SENSORS

Sensors in Pythagoras represent methods of detection. Each agent can carry up to three sensors with what the user's manual describes as signature bands. These signature bands represent a capability of the sensor. For example, a blue agent may carry sensor A, which represents line-of-sight with a signature band of 0 to 1000 meters. He may also carry sensor B, which represents a thermal detection device with an identical signature band of 0 to 1000 meters. Sensor A may not detect an enemy agent at night or hidden behind some obstruction, where sensor B will. For this simulation, all agents are equipped with only one sensor that represents line-of-sight up to 1000 meters.

G.   ATTRIBUTE CHANGERS

Attribute changers are objects that change agent color and attribute values (Northrop Grumman, 2008). There are 10 "generic" attributes in addition to the three colors previously mentioned. This allows sufficient flexibility for the user to define what these attributes represent for their scenario (e.g., fear, fatigue, courage, or something else that when collected to a certain point could induce a behavior change). These attribute changers are linked to items in Pythagoras, such as weapons. Attribute changers can also be linked to an incident, such as being hit with a voice command or NLW. These attribute changers are used in the scenario to change agent characteristics appropriately in response to certain events. For example, the attribute changer "Become a Little More Red" is tied to a civilian throwing a rock. This attribute changer causes a five increment increase in redness as well as a five increment decrease in blueness.

H. ALTERNATE BEHAVIORS

The Pythagoras user's manual describes alternate behaviors as "new behaviors that an agent will follow-once a triggered event is activated" (Northrop Grumman, 2008, p. 14–1). These behaviors are linked to triggers for each agent. For instance, the "Willing to Shoot M4" alternate behavior is implemented when the friendly casualty trigger occurs. These behaviors allow for accurate adherence to ROE for blue agents and reasonable reactions to additional events for other agents.

I. AGENTS

The agent is the most detailed component of the model. Figure 15 shows the variety of characteristics and properties one can build into an agent in Pythagoras. Defining appropriate agent behaviors, triggers, and attributes is the most important part of the model, as agent behaviors have a critical role in determining the overall outcome of the simulation.
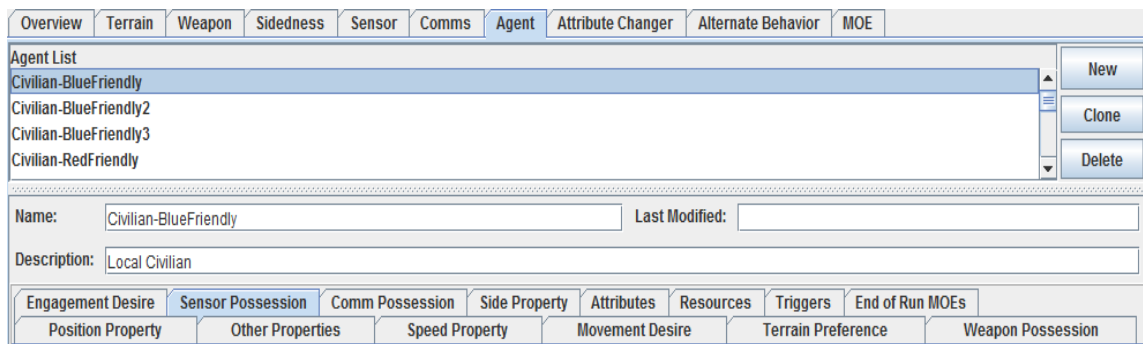
Figure 15. Agent Characteristics Menu.

1. Blue Agents

Blue agents represent the Marines in this scenario. There are three blue agents per post, for a total of 18 Marines stationed around the embassy perimeter. All Marines have identical characteristics, attributes, triggers, and sensors. This uniformity is to represent a unit with consistent capabilities throughout adhering to an ROE. The only difference between blue agents is the weapons they possess; not every agent has a NLW equipped for

every scenario variation. The number of blue agents equipped with the ANLM is varied as part of the experimental design; this is discussed in more detail in the experiment chapter.

a.   *General Behaviors*

The overarching goal of all blue agents is to influence the crowds outside the embassy to disperse with the least amount of physical force as possible. In order to accomplish this, blue agents will adhere to a strict ROE. Only verbal commands will be used first, followed by the ANLM, followed by lethal force if absolutely necessary.

b.   *Sensors and Triggers*

Blue agents are all equipped with the same sensor. This sensor enables them to visually see the red and civilian agents, but not detect each other. This is a workaround in Pythagoras to ensure that blue loudspeaker shots are not being wasted on fellow blue agents. For this scenario, blue movement does not depend on being able to detect each other, so it was considered acceptable.

Blue agent icons begin as blue circles. Blue agents desire to shoot the least lethal weapon they possess; therefore, they initially only shoot the loudspeaker weapon at all other agent types in order to attempt to influence them. If they can influence the agents into turning blue enough, those agents will leave the demonstration area. If a blue agent has more than one rock fired at him, his security posture becomes more aggressive and the icon changes to a blue square. That specific blue agent is now willing to fire a NLW. This behavior does not affect the state of blue agents on other posts. Blue agents will resist going lethal as long as possible. Once there is any blue agent casualty, all blue agents switch to lethal means and the icon changes to an inverted blue triangle. The blue agent behaviors and triggers are depicted in Figure 16.

Blue Agent Behavioral Flow Chart
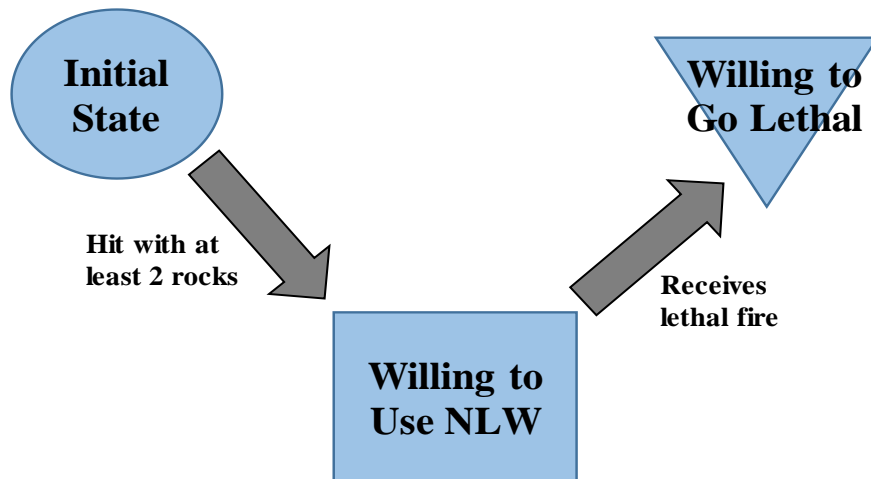
Figure 16. Behavior of Blue Agents Based on Triggers.

2.   Red Agents

Red agents represent the aggressors in the scenario. They are the minority in the crowd. Their goal is to exert influence on the civilians to cause the security situation to degrade for the blue agents. They have a low desire to hold fire and once they gain enough support from the crowd, will take lethal shots at the blue force. While in reality, an instigator would only have a rough idea how many individuals in the crowd support his cause, for the purposes of this research, red agents have perfect knowledge of crowd support. The red agents are dispersed throughout the three crowds, when total numbers allow. The total number of red agents the scenario begins with is varied to see the effect that this plays on scenario lethality.

a.   General Behaviors

The goal of the red agents is to kill the blue agents, and through this influence removal of all U.S. personnel from the embassy. The red agents are not inherently suicidal. While they want to use lethal force against blue forces, they will not do so without a storyline that supports the escalation and enough local backing. They are initially instigators, not outright combatants. As one can safely assume blue forces will

not be influenced by red forces to shift allegiances or acquiesce in their mission, the same assumption can be made of red forces. Red agents are not influenced by blue forces to yield in the pursuit of their stated mission.

b. *Sensors and Triggers*

Red agents are equipped with a different sensor than blue agents, but it also represents visual sight that allows them to see and target any other agent in their line-of-sight. The only difference is that the sensor does not have the same reach as the blue sensor due to the fact that blue agents are in an elevated position.

Red agent icons begin as red circles. While red agents want to kill blue forces, they will not go lethal immediately. They first have to meet conditions that will allow them to do so. They will first use their loudspeaker weapon to influence the crowd to their cause as well as the rock weapon to instigate blue forces. Once a red agent is hit with a NLW, he will be stunned for 30 seconds and the icon will become a red square. This indicates that the red agent would like to use the AK-47, but needs to find sufficient support from the crowd before actually going lethal. Once 10% of the crowd achieves the appropriate level of redness, the agent icon becomes an inverted red triangle and he becomes willing to use the AK-47. If there is already enough support in the crowd after a red agent is hit with a NLW, it is possible for them to go straight to the lethal stage. Once in this stage, there is no constraint on the number of lethal shots a red agent may take. These behaviors and triggers are displayed in Figure 17.

Red Agent Behavioral Flow Chart
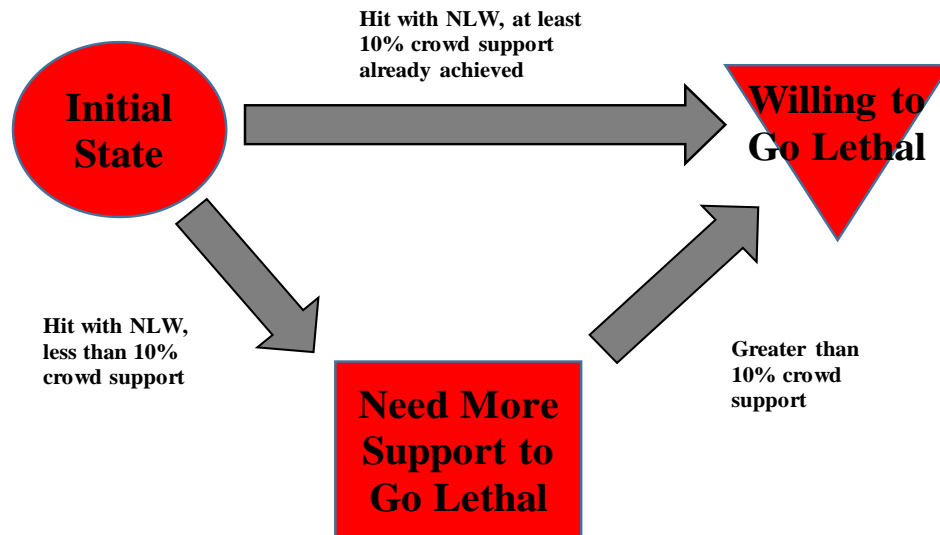
Figure 17.   Behavior of Red Agents Based on Triggers.

3.   Civilian Agents

There are two types of civilian agents in the model, blue-friendly and red friendly. The behaviors for these agents are more complex than the others due to both red and blue forces competing to influence the actions of all civilian agents. Civilian agents are 50% detectable to blue agent sensors, but when an individual takes action against a blue agent, such as throwing a rock, they draw attention to themselves and become 100% detectable. Additionally, all civilian agents are equipped with the same sensor. They themselves are invisible to this sensor, preventing any civilians from shooting at each other. The behaviors and triggers for each type of civilian are described below.

a.   *Blue-Friendly Civilian Behaviors and Triggers*

Blue-friendly civilian icons begin as dark blue diamonds of various shades. Since most blue-friendly civilians have some redness in them, the colors blend to indicate level of sidedness. The blue-friendly agents with higher levels of redness appear purplish in color. With higher levels of blueness, the blue-friendly agents are more apt to listen to blue agents; however, they can be influenced by red agents and it is possible for them to shift allegiances.

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There are multiple triggers that sway the actions and sidedness of blue-friendly agents. If a blue-friendly agent is hit with a blue voice command, they heed the warning from the blue force. This causes the icon to change to a vertical bowtie and the agent moves out of the area. Additionally, once they heed the warning they become invisible to the blue agent sensor; this ensures blue agents do not waste any more attention on a compliant civilian. If a blue-friendly agent is hit with an ANLM blast, this also triggers him into the heed warning state. Blue-friendly civilians are armed with rocks, but they initially have a high hold fire desire. If they are influenced to throw a rock, that triggers an immediate sidedness shift and the agent's redness increases. If a blue-friendly agent's redness increases past the 250 threshold they become much more willing to throw a rock. Table 4 summarizes the states and triggers for blue-friendly civilian agents.

Table 4.   Blue-Friendly Civilian Triggers and Behaviors

Trigger	Agent State	Agent Icon	Agent Behaviors
N/A	Initial State		Generally compliant to blue forces. Armed with rocks, but have a high hold fire desire.
Hit with Blue Voice	Heed Blue Force Warning		Will listen to blue force warnings and leave the area.
Hit with NLW	Heed Blue Force Warning		As long as agent redness does not exceed 250, agent will listen to blue force warnings and leave the area.
Redness Reaches 250	More Likely to Throw Rock		Hold fire desire decreases to .05. Agents become much more likely to engage blue force with rocks.

b.   *Red-Friendly Civilian Behaviors and Triggers*

The red-friendly civilian class is the most complex to model. Since red-friendly agents are inherently more belligerent than their blue-friendly counterparts, there is more variability built into the behavior of this agent class. The red-friendly agent icon begins as a maroon "X." Similar to the blue-friendly icons, the hue of maroon is varied depending on the level of blueness inherent to each agent. Red-friendly agents are less likely to be swayed by blue forces and more likely to be goaded into action by red forces. To model the effect of "group think," each red-friendly agent is equipped with a weapon that shoots five increments of red sidedness at other agents within a 200-meter radius.

This weapon is slow fire and is meant to represent the effect a crowd can have on individual decision making.

In addition to higher variability within the individual behaviors, red-friendly agents also have a wider range of actions they may take in response to different triggers. All red-friendly agents have a low hold fire desire and are initially equipped with rocks. Due to the varying degrees of redness at the start of the simulation, some red-friendly agents are immediately willing to throw rocks while others need to be influenced and become further red in order to take action against blue forces. When a red-friendly agent is hit by either a red or blue voice command their sidedness is affected. However, there is more randomness built into how much the sidedness is affected for red-friendly than blue-friendly in order to account for the real life unpredictability of an unfriendly civilian. When hit with a blue voice command, there is additional variability built into the agents' reactions. They may stop, move away, or ignore the command and continue their actions.

If a red-friendly agent is hit with an ANLM blast, they will be immobile for 30 seconds and their sidedness is affected in a manner similar to the voice commands in that there is uncertainty in the effect. They will also enter a state in which they are more likely to throw a rock. Every rock thrown initiates a higher level of redness within the agent. If an agent's redness reaches 250, the icon becomes an inverted red triangle and the agent enters a state in which they are willing to shoot an AK-47. Conversely, if an agent's blueness reaches 200, that is the trigger to enter the heed warning state. The icon will shift color towards blue, turn into a vertical bow tie, and the agent will leave the area. Table 5 summarizes the states and triggers for red-friendly civilian agents.

Table 5.   Red-Friendly Civilian Triggers and Behaviors

Trigger	Agent State	Agent Icon	Agent Behaviors
N/A	Initial State		Some may be willing to throw rocks if initial redness value is high enough. Generally not compliant to blue forces, shoots a red color increment of 5 at other agents in the crowd at a slow rate. High variability in sidedness reactions.
Hit with NLW	More Likely to Throw Rock		Sidedness changes by ± 15 for either color. Increased desire to engage blue forces, not willing to use lethal force yet. Every rock thrown increases the agents redness.
Redness Reaches 250	Willing to Shoot AK-47		Will still throw rocks, but willing to use lethal force if there is more than 10% crowd support.
Blueness Reaches 200	Heed Blue Force Warning		Will listen to blue force warnings and leave the area.

J.   MODEL LIMITATIONS

1.   Tactical Realities

There are certain tactical realities that are not simple to implement within Pythagoras. Due to certain simulation restrictions within the modeling environment, some issues require creative workarounds that have crude implementations with varying degrees of success. For example, there is no way to define a sector of fire for each blue force post. In order to address this issue, the embassy has constructive internal walls that prevent blue agents from shooting through them. These walls restrict blue agent firing to certain angles. However, in building this model a bug in Pythagoras was revealed that sometimes allows agents to shoot through these walls anyway. While this slightly detracts from tactical reality, it does not appear to affect the results of the research.

2.   Human Behavior

It is not possible to truly model the intricacies and unpredictability of the individual human mind. The best that can be done is to define a reasonable range of behaviors and reactions based on a common group identification. This allows us to glean generalities and insights for the modeled situation, not necessarily detailed facts.

3.   ROE

Defining ROE is not as simple as hard-coding a list of rules within the environment. Similar to tactical realities, Pythagoras requires creative implementation to establish ROE that can leave some intricacies out. For example, in this scenario it is established that once a blue agent is hit with two rocks, that agent will use a NLW. In reality, the ROE would not have a hard number attached to it and would likely state something more along the lines that the force may use NLW once there is impending danger to a Marine. The model takes the human aspect out of the decision.

V. THE EXPERIMENT

It does not make any difference how beautiful your guess is. It does not make any difference how smart you are, who made the guess, or what his name is—if it disagrees with experiment it is wrong. That is all there is to it.

—Richard Feynman
Lecture at Cornell University, November 19, 1964

A. MEASURES OF EFFECTIVENESS

The Department of Defense Modeling and Simulation Coordination Office (DMSCO) defines an MOE as "a qualitative or quantitative measure of the performance of a model or simulation or a characteristic that indicates the degree to which it performs the task or meets an operational objective or requirement under specified conditions" (2016, para. 4). The primary MOE for this model, also referred to as the response variable, is the mean number of lethal shots fired by all agents for each design point. This is the measurement we use to determine whether the ANLM successfully reduces lethality in the embassy security scenario.

B. FACTORS

In every simulation, there are inputs of particular interest to the scenario. These inputs are referred to as factors. The point in examining these factors at different levels is to determine how and to what extent that they affect the end results. There are four primary factors that are varied throughout the experiment, they are shown in Table 6.

Table 6.   Experimental Factors

Factor	Min Value	Max Value
Min Engagement Range for ANLM	15m	35m
Number of NLW systems per post	0	3
Starting number of red agents	1	20
Starting percentage of civilians that are blue-friendly	10%	90%

1.   ANLM Minimum Engagement Range

One of the key performance parameters set forth by the project manager for the ANLM is its minimum engagement range. The required threshold for fielding the munition is 35 meters, which has been successfully met. The operational desire for the minimum engagement range is 15 meters. By varying this factor between these two values, the experiment will explore if there is a significant advantage gained in achieving a 15-meter minimum engagement range. Furthermore, the experiment will investigate if there is a critical point for the minimum range where no further advantage is gained by reducing the minimum engagement range below that point. This will provide insights to the JNLWD as to whether or not they should actively pursue the development of a munition with decreased engagement range.

2.   Number of NLW Systems per Post

One aspect of this mission that requires exploration is how many weapon systems to bring and how many to assign to each post. While the weapon system itself is not necessarily an issue, being a standard M203 attachment for a service rifle, the number of weapon systems per post determines a number of logistical considerations, such as how much ammunition to bring and required repair parts. Additionally, varying the number of NLW systems per post will give tactical insight. For this factor, the number of NLWs is constant between posts, meaning the scenario will either have 0, 6, 12, or 18 total NLW systems.

3. Initial Number of Red Agents

The red agents achieve their goal of engaging the blue force by influencing the civilians in the crowd. By changing the initial number of red agents the simulations start with, some insight can be gained as to how the tactical situation is effected by the initial population of adversaries. This insight can be used by tactical unit commanders for planning and course of action (COA) development purposes before setting foot on the ground. This type of planning and insight provides commanders with the ability to be flexible and make quick tactical adjustments once in country.

4. Initial Percentage of Civilians that are Blue-Friendly

When an ambassador requests an embassy reinforcement force from the combatant commander, there is a deteriorating local situation. However, to what level the situation is deteriorated can fluctuate greatly. By varying how "permissive" the environment is, additional tactical insights can be gained. This can help tactical unit commanders in mission planning and COA development, as with the previous factor.

C. DESIGN OF EXPERIMENTS

In writing on how to design simulation experiments, Dr. Susan Sanchez states that "experimental designs indicate how to vary the settings of factors to see whether and how they affect the response" (2005, p. 47). The goal of the design of experiments (DOE) is to establish a design that will efficiently explore the various combinations of factor levels in a manner that allows for the experimenter to gain accurate insights into how the factors affect the response. To achieve this, the design should fill as much of the design space as possible. An effective space-filling design is one that minimizes the amount of un-sampled regions in the design space (Cioppa & Lucas, 2007). One method to establish a space-filling design is to use a nearly orthogonal Latin hypercube (NOLH). The NOLH was established by Dr. Thomas Cioppa in order to establish a method for creating efficient designs for large scale, high dimensional military simulations (Cioppa, 2002). To find out more about how the NOLH is created, refer to the dissertation by Cioppa listed in the references. For more flexible NOLHs, refer to Hernandez et al. (2012) and if a second order NOLH is required, see MacCalman et al. (2017).

D.   THE DESIGN

Two methodologies are used to establish the design for this experiment. First, a NOLH is used to establish design points for the following factors: minimum engagement range, number of red agents, and percentage of blue-friendly civilians. This results in 65 design points. This design is then crossed with the four factor levels for the number of NLWs per post, giving a total of 260 design points for the experiment. The coverage of the design space is depicted in Figure 18. From this, it appears that the design samples well from all regions of the design space. Each design point was run 40 times, for a total of 10,400 simulation runs. This replication allows for the stochastic nature of the model to give a range of results. Analysis can then be done on these results and conclusions can be drawn for the overall scenario.
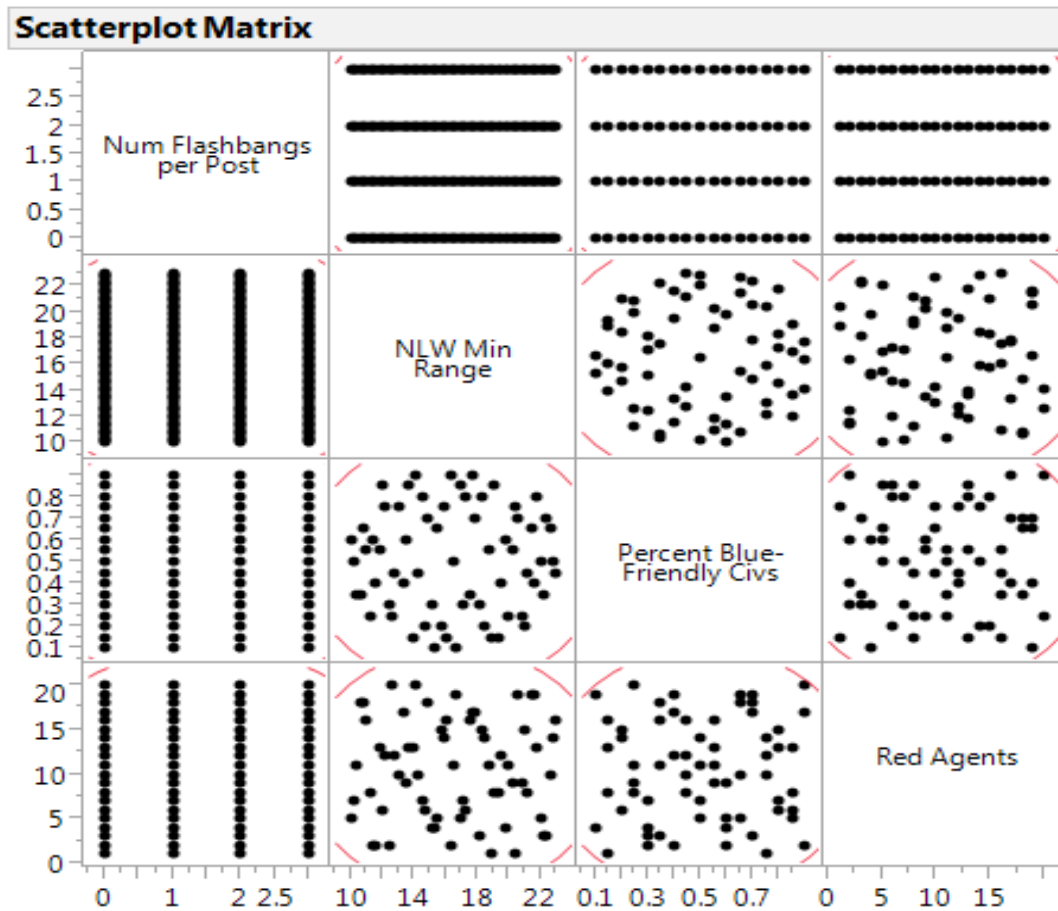
Figure 18. Crossed NOLH Design Coverage.

E.   CROSSED NOLH VERSUS FULL FACTORIAL DESIGN

To get a completely space-filling DOE a full factorial design must be used. Full factorial designs explore every possible combination of factor levels, so as levels and factors grow, the number of design points increases exponentially. To gain an understanding of the effectiveness of the crossed NOLH design, a comparison of run times can be used. For this experiment, the crossed NOLH design with 260 design points took approximately 2.3 hours to run on a supercomputer run by the Simulation Experiments and Efficient Design (SEED) Center at the Naval Postgraduate School. For more information on the SEED Center, please reference their homepage at harvest.nps.edu. The SEED cluster uses 151 processors in parallel, which dramatically reduces the amount of time required to run over 10,000 simulations. A full factorial design for the same factors and levels results in 91,120 design points. This design would take 33.5 days to run on the same SEED cluster. While this is not an impracticable length of time, under the time constraints of this study running simulations for over a month straight is not feasible. The crossed NOLH design allows for results that are practical and comparable to a full factorial design without the dramatically increased time and computational requirements.

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VI. RESULTS AND ANALYSIS

It's the analyst, not the model, that produces important useful results. Improve the former before the latter.

—Seth Bonder
Army Operations Research: Historical Perspectives and Lessons Learned,
January 2002

A. MODEL AUTHENTICATION

Before running a full experiment, it is necessary to verify that the model is behaving as intended. There are many values that the model requires as input, including weapons ranges, rates of fire, and behavioral attributes. These values are difficult to determine without actually seeing how they affect the model behavior. In order to ensure these difficult values are set at reasonable levels and ranges, a preliminary DOE is conducted. The DOE includes only the high and low values of each factor. This 16-point design allows for the creation of a "bounding box," or extreme values in which the results for all other factor levels will presumably fall between. The experiment results establish a baseline for the model and determine whether adjustments are needed before running the full design. To determine whether adjustments are needed, I used personal knowledge of military operations to verify that the model behaviors made sense.

Each experiment was replicated 20 times for a total of 320 simulations. The outcome of the endpoint design resulted in the following:

- Having 90% blue-friendly civilian agents decreases the average number of lethal shots from the 10% blue-friendly level.

- Having three NLW systems per post reduces the mean number of lethal shots fired.

- Having a closer minimum engagement range appears to have a small effect on the number of lethal rounds fired.

Another insight gained from the endpoint design is an initial idea of what factors interact with one another. Figure 19 depicts the interaction profile plots for all the factors.

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From these profiles, there appears to be substantial interactions between number of NLWs and minimum engagement range, number of NLWs and the percent of blue-friendly civilians, minimum engagement range and total number of red agents, and percent blue-friendly civilians and number of red agents.
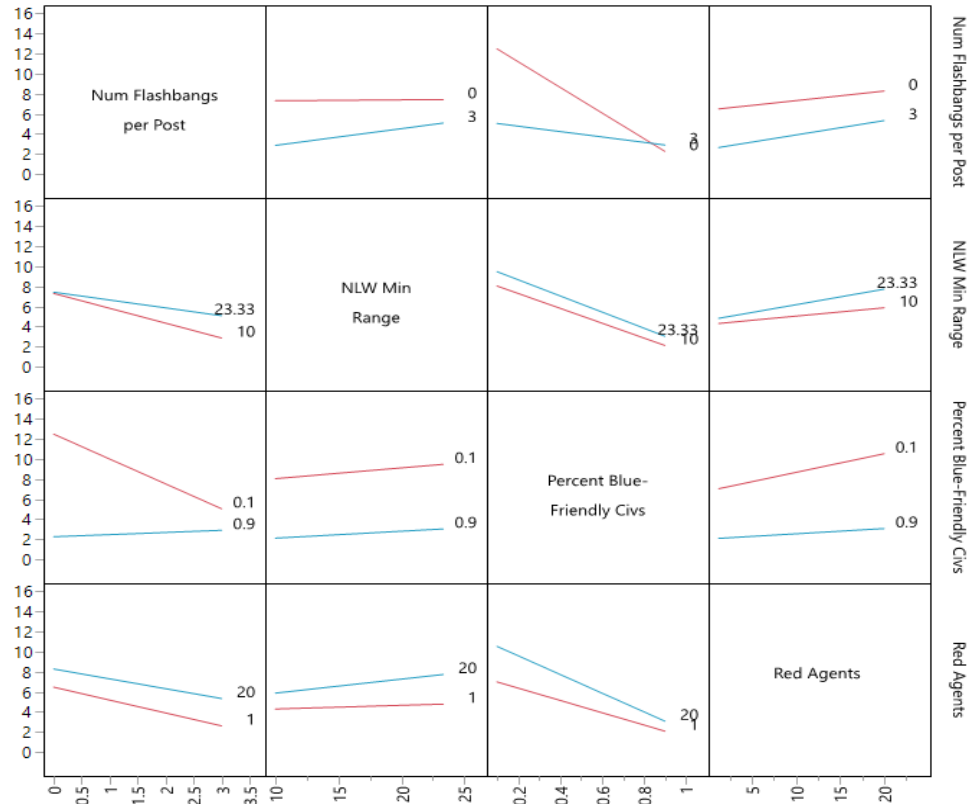
The more deviance from parallel the two lines show, the higher the indication there is an interaction between the factors. If the lines are parallel, there is no indication of an interaction between the factors.

Figure 19. Interaction Profiles from Endpoint Design Runs.

From the endpoint design, the only adjustment required before running the full experiment was to increase the level of crowd support necessary to fire a lethal shot. Red agents were too quick to use lethal force; the environment was not reflective of the intended scenario of red agents being agitators versus being outright hostile. The initial requirement was for a red agent to only need six agents for support. The requirement was changed to needing 10% crowd support. With this adjustment, the full DOE is ready to be run.

B.   THE DATA

1.   Data Collection

Upon the conclusion of all design runs, a comma separated values (CSV) file with the outputs from each experiment is produced. This file contains over 2.9 million data points. There is a row per run for a total of 10,400 rows and 279 columns that contain data points for a number of different aspects of the scenario, the most important of which is the total number of lethal shots fired.

2.   Analysis Software

To analyze the data, it is imported into JMP Statistical Discovery Software. JMP allows users to explore and display data and conduct statistical analysis in an easy to use GUI (JMP, 2009). In particular, JMP allows the creation of data visualization tools in which users can manipulate data and see the effects immediately. This is a powerful, efficient, and interactive analysis tool that permits users to make statistical deductions from large data sets (JMP, 2017).

C.   REGRESSION

Regression is an important tool to build predictive models. Regression mathematically determines the impact of the input (predictor) variables on the response variable. The *Harvard Business Review* describes the effects of regression in layman's terms, they state "It answers these questions: Which factors matter most? Which can we ignore? How do those factors interact with each other? And, perhaps most importantly, how certain are we about all of these factors" (Gallo, 2015, para. 4). In order to answer these questions, three statistical measures are used. They are as follows:

- Adjusted R^2: This is a statistical measure of how much variation is explained by the model, with a penalty function for adding more variables. The closer to 100%, the better the model generally fits the data. These variables need to be analyzed in conjunction with residual plots, as they do not account for possible bias in the model coefficient estimates and predictions (Frost, 2013).

- F-statistic: An analysis of variance (ANOVA) F-test is a formal test that determines whether the relationship of the response variable to the predictor

variables is statistically significant (Sickinger, 2006). For this research, all formal tests are conducted at the 95% confidence level.

- T-statistic: A Student's T-test is performed on each individual predictor variable to determine whether it is significant to the model in the presence of all the other predictor variables.

1. Stepwise Regression

Deciding which input variables and interactions between variables are important can be an arduous and subjective process, especially for larger scale models that have numerous inputs. Stepwise regression is used "when there is little theory to guide the selection of terms or you want to improve a model's prediction performance by reducing the variance caused by estimating unnecessary terms" (JMP, n.d.-b, para. 1). Initially, all primary factors and two-way interactions are built into the model. Stepwise regression cycles through all of these variables and determines which terms are significant. These terms are then used in a standard least squares regression model. The predictors determined as significant for this model are shown in Figure 20. Interestingly, the stepwise regression resulted in all primary factors and two-way interactions demonstrating significance. These interactions are explored more in depth later in this chapter. To determine if there are any quadratic effects in the model, another stepwise regression was run, this time allowing for quadratics. Three additional terms were determined to be statistically significant, but not practically significant. The additional terms had no overall effect on model behaviors or results, so quadratics are not examined further in this research,

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.0610652	0.915974	7.71	<.0001*
Num Flashbangs per Post[0]	10.234327	0.300558	34.05	<.0001*
Num Flashbangs per Post[1]	2.1581731	0.300558	7.18	<.0001*
Num Flashbangs per Post[2]	-2.616058	0.300558	-8.70	<.0001*
NLW Min Range	0.5749184	0.04546	12.65	<.0001*
Percent Blue-Friendly Civs	-26.23886	0.737682	-35.57	<.0001*
Red Agents (cont)	0.6424345	0.031035	20.70	<.0001*
Num Flashbangs per Post[0]*(NLW Min Range-16.5015)	0.5717081	0.078721	7.26	<.0001*
Num Flashbangs per Post[1]*(NLW Min Range-16.5015)	0.1430006	0.078721	1.82	0.0705
Num Flashbangs per Post[2]*(NLW Min Range-16.5015)	-0.161298	0.078721	-2.05	0.0415*
Num Flashbangs per Post[0]*(Percent Blue-Friendly Civs-0.50615)	-28.11281	1.2776	-22.00	<.0001*
Num Flashbangs per Post[1]*(Percent Blue-Friendly Civs-0.50615)	-5.576976	1.2776	-4.37	<.0001*
Num Flashbangs per Post[2]*(Percent Blue-Friendly Civs-0.50615)	7.5757251	1.2776	5.93	<.0001*
Num Flashbangs per Post[0]*(Red Agents (cont)-10.5077)	0.639251	0.053754	11.89	<.0001*
Num Flashbangs per Post[1]*(Red Agents (cont)-10.5077)	0.2150966	0.053754	4.00	<.0001*
Num Flashbangs per Post[2]*(Red Agents (cont)-10.5077)	-0.160211	0.053754	-2.98	0.0032*
(NLW Min Range-16.5015)*(Percent Blue-Friendly Civs-0.50615)	-1.398884	0.251976	-5.55	<.0001*
(NLW Min Range-16.5015)*(Red Agents (cont)-10.5077)	0.0258371	0.008095	3.19	0.0016*
(Percent Blue-Friendly Civs-0.50615)*(Red Agents (cont)-10.5077)	-1.330877	0.125047	-10.64	<.0001*

Figure 20. Predictor Variables from Stepwise Regression.

2.   Standard Least Squares Regression

Standard least squares regression uses the input variables from Figure 20 to fit a model to the data. Running the regression with these predictors yields a model with a seemingly good fit. Figure 21 displays the actual versus predicted plot, the summary of fit, and the F-test results. The adjusted R^2 value for the model is .948, indicating that about 95% of the variance of the mean lethal shot values is explained by the model. This is a high R^2 value, which gives an initial indication that the model is well fit. The actual versus predicted plot visually depicts how well the model predicted the actual values of the response variable. This graph shows the values are relatively balanced about the prediction line in a fairly tight group. This supports the goodness of fit indicated by the high R^2 value. Lastly, the F-test yields a *p-value* of less than .0001, which formally validates that the model fit is statistically significant.

Summary of Fit

RSquare	0.952141
RSquare Adj	0.948566
Root Mean Square Error	2.798046
Mean of Response	10.00837
Observations (or Sum Wgts)	260

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	18	37537.188	2085.40	266.3665
Error	241	1886.804	7.83	**Prob > F**
C. Total	259	39423.991		<.0001*
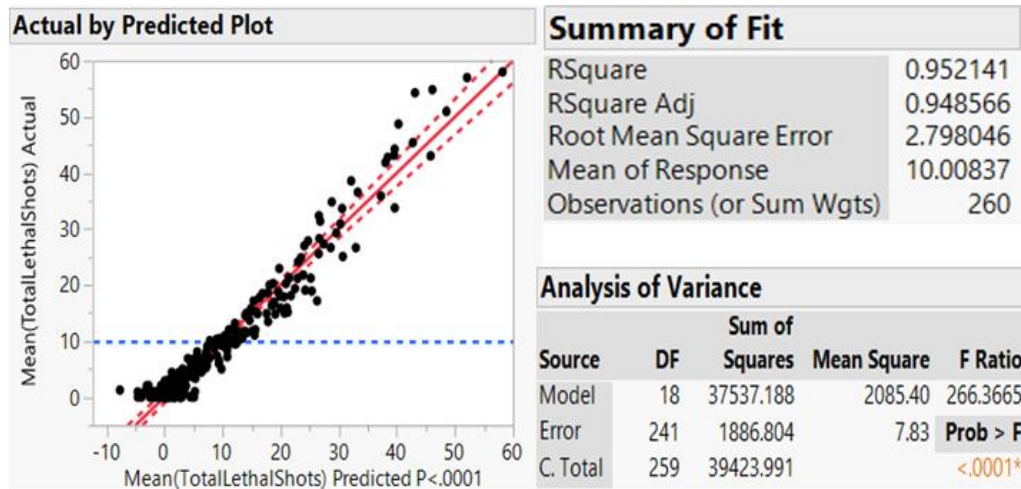
Figure 21. Actual versus Predicted Plot, Summary of Fit, and F-test Results.

To visually inspect for potential issues in the model, a residual plot is used, this plot is shown in Figure 22. Residuals are the differences between the observed and predicted values. From the plot, it appears there may be a slight issue with heteroscedasticity in the model; however, I do not believe the issue to be serious enough to require any factor transformations or have a significant impact on the model. Also, since the residuals are not normally distributed, the *p-values* will not be completely precise.

Figure 22. Plot of Residuals versus Predicted Response Variable Values.

D.   FACTOR INTERACTIONS

Figure 23 portrays the interaction profile plots for all two-way interactions in the model. With the additional runs and factor levels, the interactions are clearer than in the endpoint only design. Some key findings from the plots are as follows:
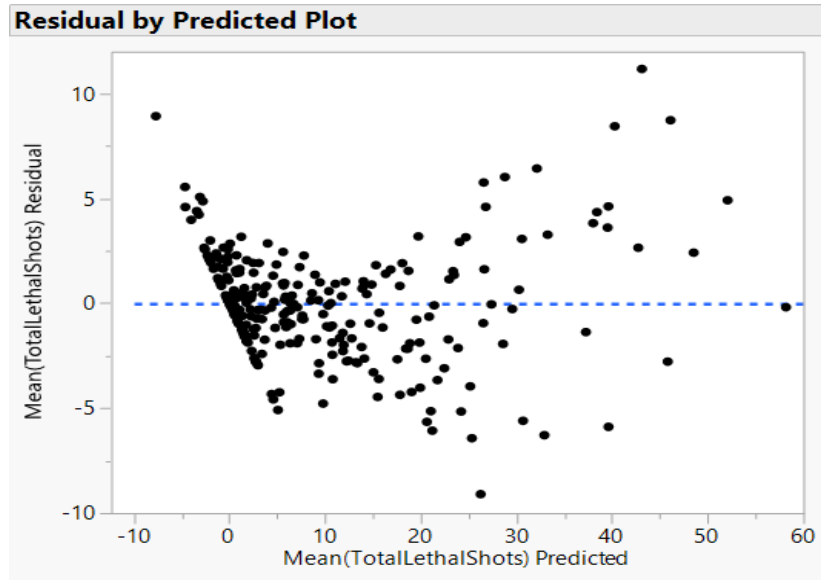
- The minimum engagement range of the ANLM has less effect on number of lethal shots fired as the total number of NLW systems per post increases.

- The percent of the civilian crowd that starts blue-friendly has a great effect on the lethality of the scenario. However, when the number of NLWs is at its highest, the friendliness of the crowd has a greatly reduced effect on lethality.

- The effect of the number of instigators in a crowd is significantly dampened if the blue-friendliness of the crowd is high.

- The number of NLW systems appears to dominate all other factors, as when it is at its maximum level of three, no other factors make a practical difference in the lethality of the scenario.

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Figure 23. Interaction Profiles for Full Design.

To further explore the interactions, the numerical variables were made into categorical variables. The categories are displayed in Table 7.

Table 7.   Categorical Factor Breakdown

Factor/Levels	Low	Medium	High
Minimum Engagement Range	< 21 meters	(21 meters, 27 meters]	> 27 meters
Percent Blue-Friendly Civilians	< 38%	(38%, 63%]	> 63%
Number of Red Agents	< 8	(8, 12]	> 12

Figure 24 displays the interaction between the number of NLW systems per post and the initial level of blue-friendly civilians in the crowd. From this profile, it is clear that in an environment with higher levels of hostility, it is best to arm the posts with a high number of ANLM capable weapons. The vertical bars around each mean represent one standard error (SE) from the mean. None of the vertical bars within each number of weapons category overlap, indicating that blue friendly density does make a distinct impact on lethality. Additionally, as the number of NLWs increase, the variability of the response variable decreases, suggesting that the number of NLWs per post is highly influential. Another indication of this is the medium SE bar overlaps with the low SE bar for each subsequent weapon system added to the post (excluding three NLWs). If the posts are armed with three NLW systems, the friendliness of the crowd has little effect.
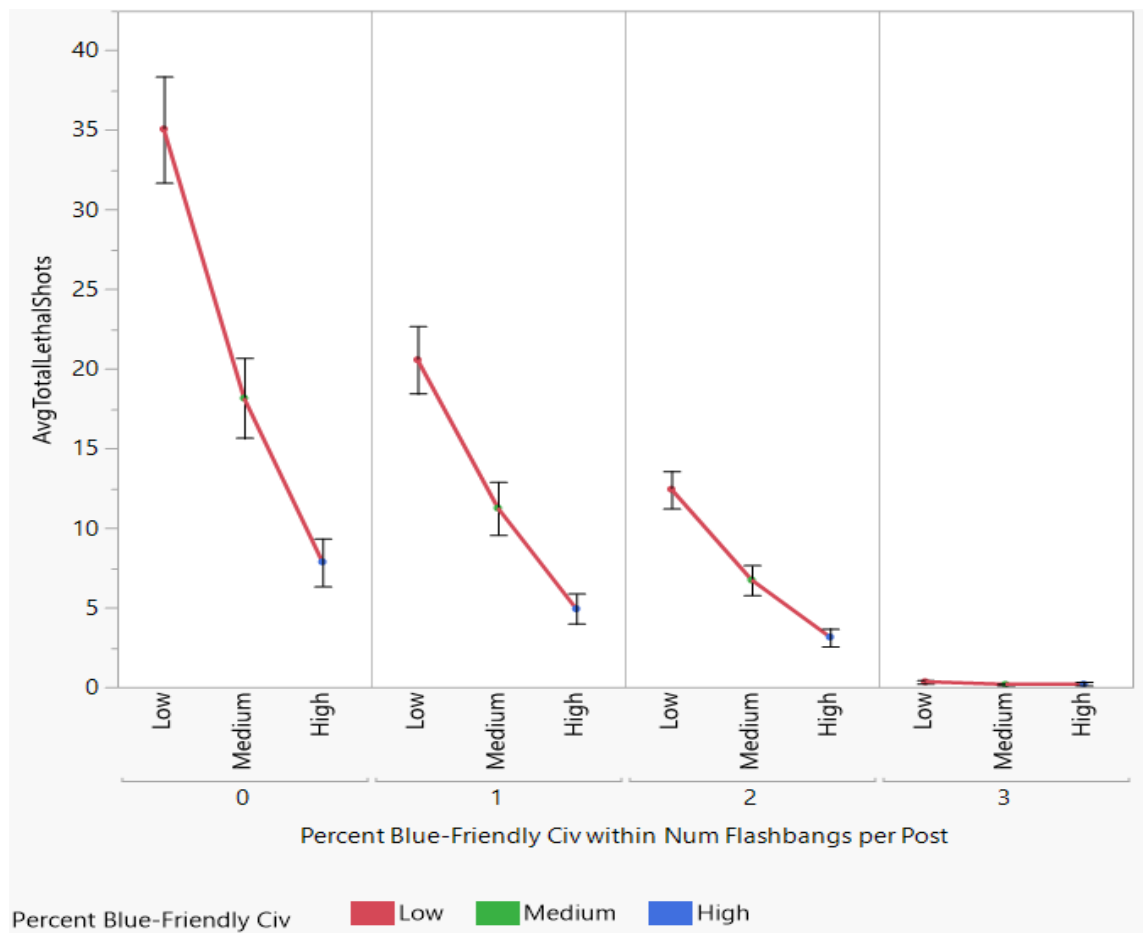

Figure 24. Interaction between Number of NLWs and Level of Blue-Friendly Civilians.

A number of tactical insights are gained from this graphic. First, it indicates that if a commander adds a weapon to each post, he can potentially negate the effect of an increased number of enemy sympathizers. Additionally, if the operational environment is known to be more friendly than not, the commander may not need to have a high number of ANLM capable weapons. However; if the environment is less permissive, the commander should try and outfit his unit with the requisite number of NLW systems.

Figure 25 shows the interaction between minimum engagement range and number of NLW systems per post. From this graph, it appears that the minimum engagement range does not have as significant an impact in reducing the mean number of lethal shots as blue-friendly level does. The SE bars within each level of NLWs per post all overlap heavily, indicating that while the mean of lethal shots decreases with the minimum engagement range, the decrease is not significant. The number of NLWs is the clearly dominant factor. This is evidenced by the fact that the mean number of lethal shots under the low minimum range category for no NLWs is almost equivalent to the mean number of lethal shots under the high minimum range category for one NLW. As the number of NLW systems per post increases, the impact of decreasing the minimum range of the ANLM is diminished. This is depicted in the decreased difference between the means within each number of NLWs category. While it is clear that deceasing the minimum engagement range impacts the mean number of lethal shots, how substantial of an impact and any key considerations are explored further later.
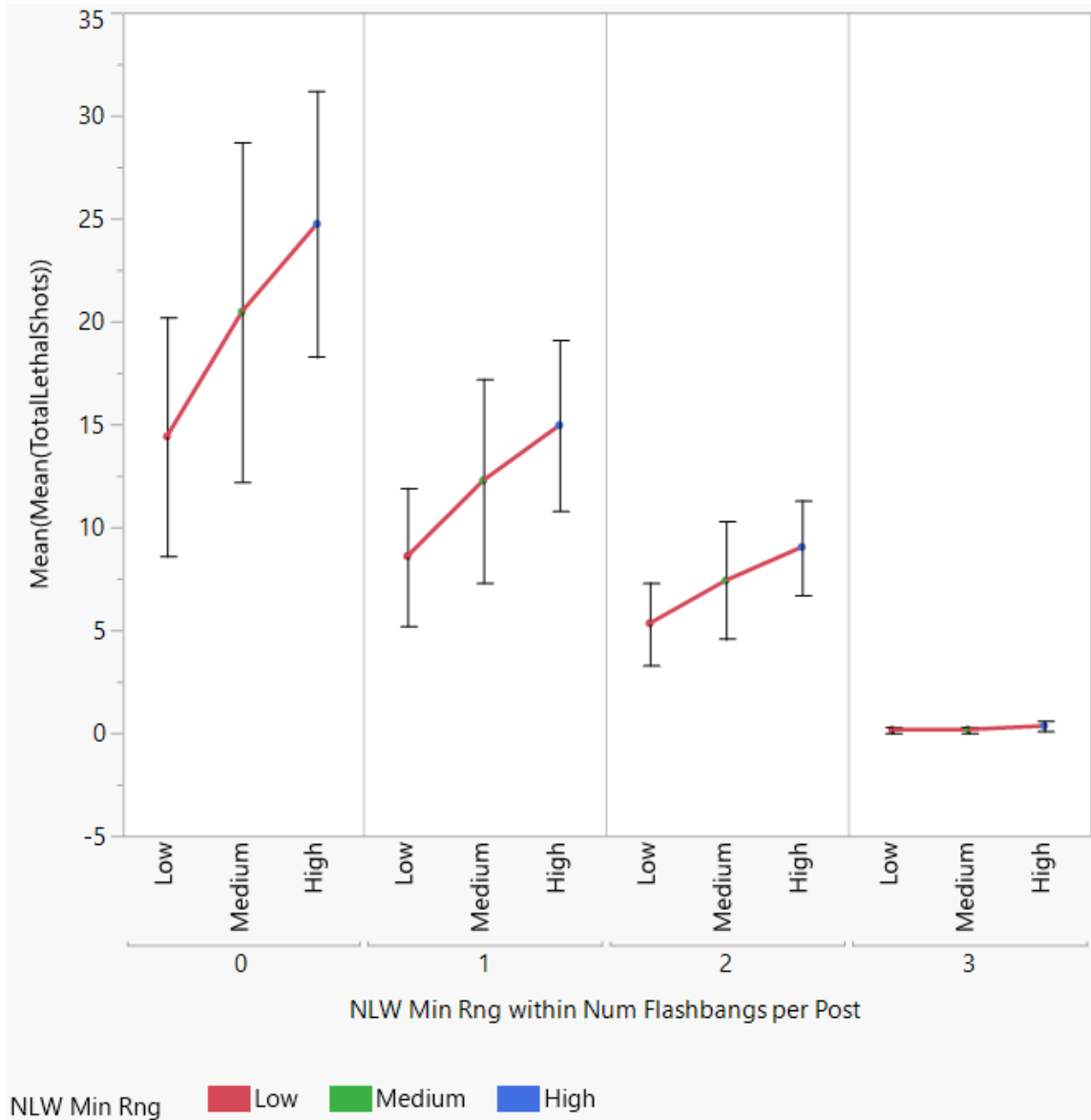
Figure 25. Interaction between Number of NLWs and Minimum Engagement
Range.

E. PARTITION ANALYSIS

1. Definition

Partition analysis is a method of dividing data based on associations between the factors and response variable. This methodology produces a partition tree in which levels of the tree indicate the next most influential factor and branch splits indicate specific points of influence. Partition analysis handles large, complex problems with relative ease,

is good at exploring relationships among variables, and produces interpretable results that use statistics to tell a story (JMP, n.d.-a). Partition trees are powerful tools that can help leaders make decisions.

2. Partition Tree

A partition tree was created from the results of the full design; this tree is shown in Figure 26. The tree has far fewer terms in it than the regression model. The total R^2 value for this model is .74, indicating that approximately 74% of the variance is explained by the model. While this is not as high as the value from the regression, it still indicates a parsimonious model from which valid inferences can be drawn.

The three levels of the tree are depicted with the blue circles. Level one indicates that the most influential factor is the number of NLWs per post. The point of influence at this level is between one and two weapons per post. The mean number of lethal shots fired when a post has two or three NLWs is approximately four. However, when the posts are only armed with one or no NLW systems, that mean jumps up drastically to approximately 16 lethal rounds fired. This is the beginning of the statistical story and the first key piece of information for decision makers to consider when planning a mission.

The second level of the tree depicts the next most influential factor. Of interest, in following the branch on the left, the next most influential factor is again the number of NLWs per post. The split occurs between three and two NLWs, with the mean being near zero lethal rounds fired if three NLWs are assigned per post. The third level has differing influential factors based on whether the second level uses two or three NLWs per post. If only two NLWs are used, the percentage of blue-friendly civilians is the next most significant factor, with the 50-percentile mark being the point of influence. If at least 50% of the civilian population is blue-friendly, the lethality of the situation is far lower than if there is less than 50% blue-friendly civilians. Of interest, after three levels of partitioning, all factors except the minimum engagement range appear in the tree. Further examination of the minimum range factor is done in the following section.
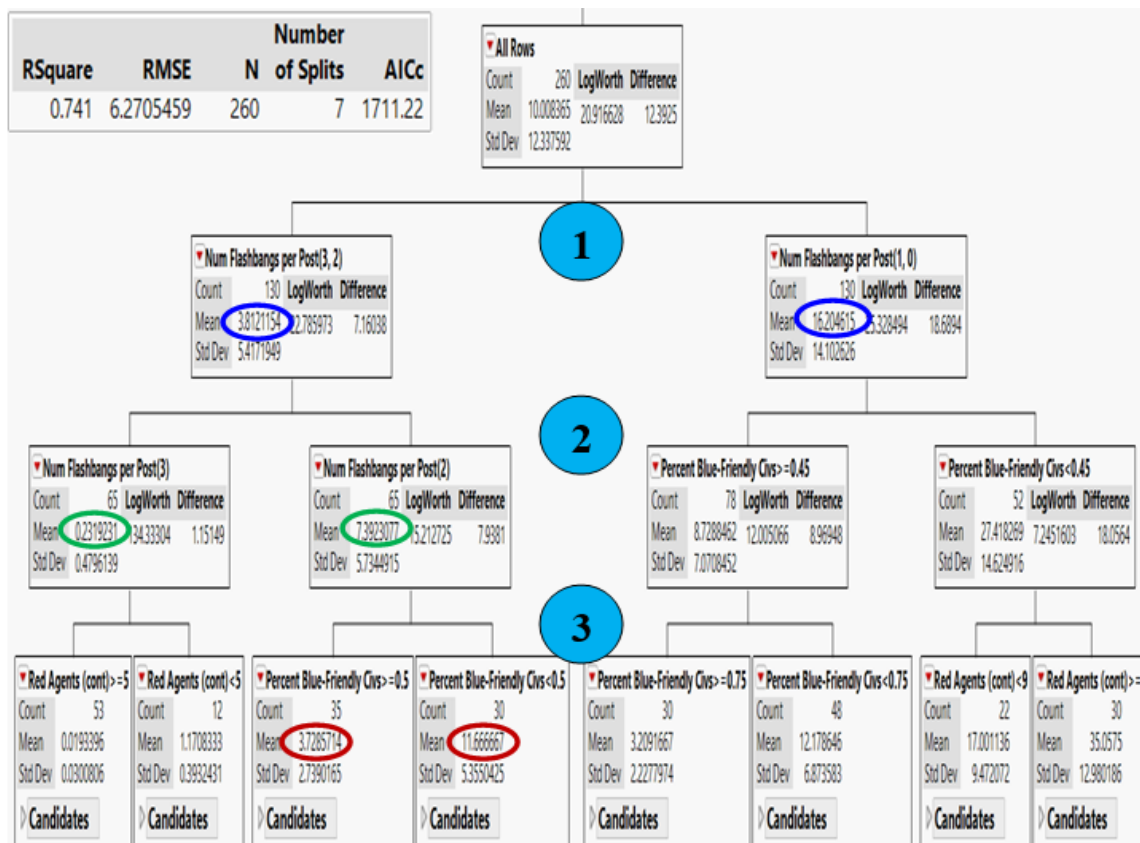
Figure 26. Three-Level Partition Tree on Full DOE Results.

3. Application

The partition tree is particularly useful in aiding leaders conducting mission analysis. For instance, if intelligence suggests that no less than 60% of the population is friendly to U.S. forces, that can drive the decision on the tactical load out. Depending on asset availability, it may be worth the increased risk to only take enough NLW systems for two per post. That lethality increase is not drastic; however, if less than 50% of the civilians are friendly, the significant risk increase can drive the commander to request additional weapon systems and munitions to arm each post with an extra NLW.

F. EXPLORING MINIMUM ENGAGEMENT RANGE REQUIREMENTS

From the previous analysis, it is clear that the minimum engagement range of the ANLM, while not one of the largest contributors, does have an impact on the lethality of the scenario. In order to provide JNLWD insight into the benefit of reducing the

minimum engagement range, further analysis is needed. To conduct this analysis, all other factors are held constant. While the results of this analysis will only be directly applicable to the specific scenario built for this instance, combined with the previously discovered interactions they will allow for a level of insight into the effect of minimum engagement range as a whole.

The levels for these factors were chosen based on a scenario developed from the partition tree. This general scenario is depicted in Figure 27 and the specific factor values are shown in Table 8. The scenario from the partition tree and the specific values were chosen because they reflect what is a reasonably likely tactical situation.
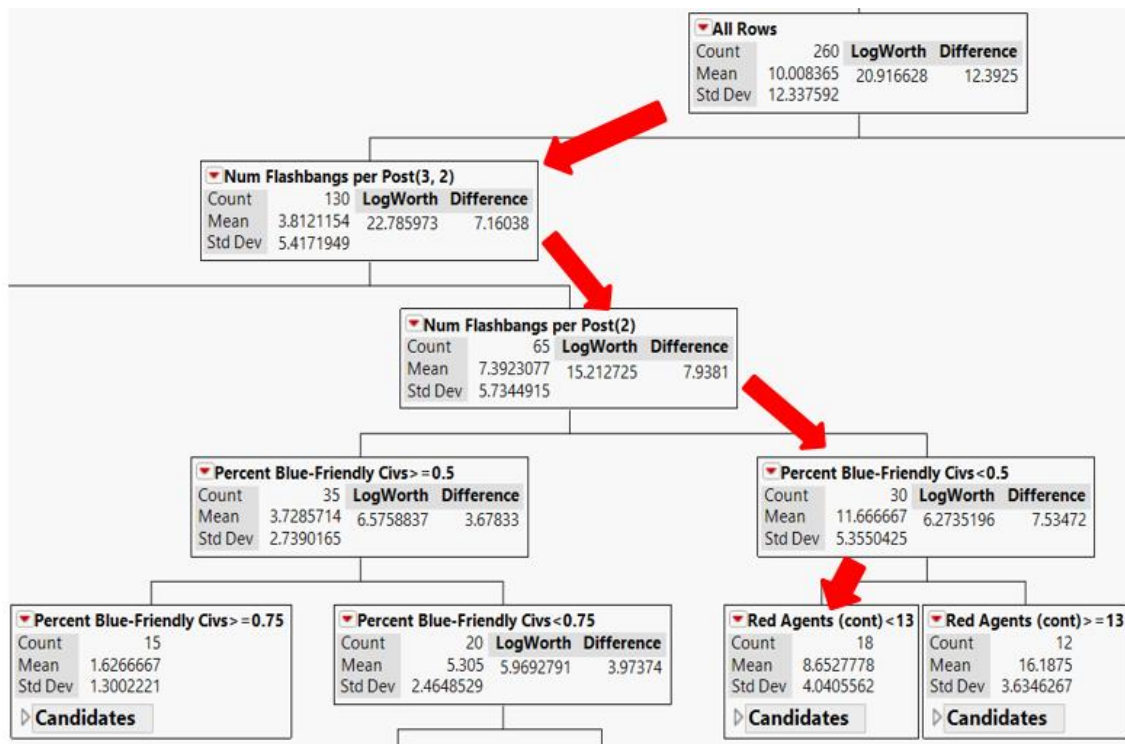

Figure 27. Scenario Development through Partition Tree.

Table 8. Factor Values for Minimum Range Experiment.

Factor	Min Value
Min Engagement Range for ANLM	15m-25m (1m increments)
Number of NLW systems per post	2
Starting number of red agents	12
Starting percentage of civilians that are blue-friendly	49%

The overall goal of this analysis is to determine if there is a specific point in which further decreasing the minimum range no longer yields significant tactical benefit. Figure 28 displays the effect minimum range has on lethality at the factor levels in Table 8.The blue line is the smoothed data output, the grey shadow surrounding it represents the 95% confidence interval for the mean number of lethal shots fired. While there is a clear decrease in mean number of lethal shots from 35 meters to 20 meters, it is only a decrease of approximately two lethal shots from 11 to 9. Additionally, the confidence intervals overlap, indicating there is really not much difference between the 35 meter and 20 meter ranges. However, there is a much steeper decline in lethal shots from 20 meters to 15 meters. In that five-meter difference, the mean number of lethal shots drops significantly, from approximately 9 to 6. At 17.5 meters, the confidence interval no longer overlaps with the interval at 20 meters.
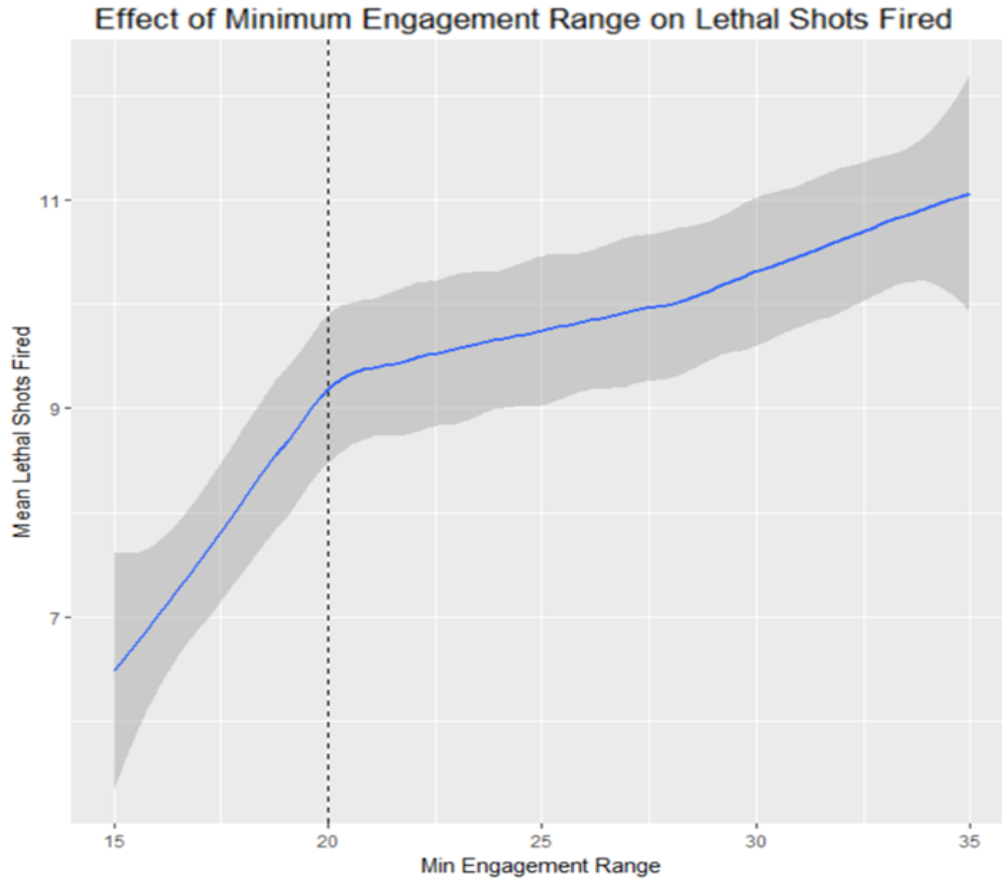
Figure 28. Minimum Engagement Range Effect on Lethality.

Analyzing Figure 28, it appears that minimum range does not have a significant effect on lethality until about the 17–19 meter range under the given conditions. This will vary based on the levels of the other parameters, but the general insight gained from this analysis is that minimum range will not have a great impact on reducing lethality in this scenario unless it is reduced to less than 20 meters. Reducing the minimum engagement range to 15 meters would give warfighters a marked increase in capability.

VII. CONCLUSIONS AND RECOMMENDATIONS

Non-lethal capabilities offer relevance and utility to operations in which civilian casualty avoidance plays an increasingly strategic role.

—General Robert B. Neller,
DOD Non-Lethal Weapons Executive Agent Planning Guidance 2016

A. EFFICACY OF AGENT-BASED SIMULATION

Using an agent-based model (ABM) to simulate an embassy demonstration offers decision makers a flexible approach to analyze potential outcomes with the human element taken into consideration. "The ability to analyze thousands of different situations and variable combinations provides the analyst with the ability to gain a much more thorough knowledge of a problem than can be provided by subject matter experts or point estimates" (Roginski, 2006, p. 121). Additionally, using agent-based simulation (ABS) in combination with the ability to construct and implement efficient designs and modern computing capabilities allows analysts and decision makers to explore a wide range of possible conditions. From these results, analysts can scope down to any interesting areas and do more focused analysis on a specific set of variables.

B. REDUCING LETHALITY WITH THE ANLM

Based on this research, the ANLM does successfully reduce the lethality of the scenario. Figure 29 illustrates this reduction in lethality. As the number of weapons systems per post increases, the mean number of lethal shots per scenario decreases, as indicated by the green line in each column. Additionally, increasing the number of NLWs decreases the variability in lethal shots taken. At zero NLWs, the scenario results range from no lethal shots to over 70. This is a wide range and indicates the high level of uncertainty that comes with not having any non-lethal capabilities. The variability decreases drastically as the number of NLWs increases.
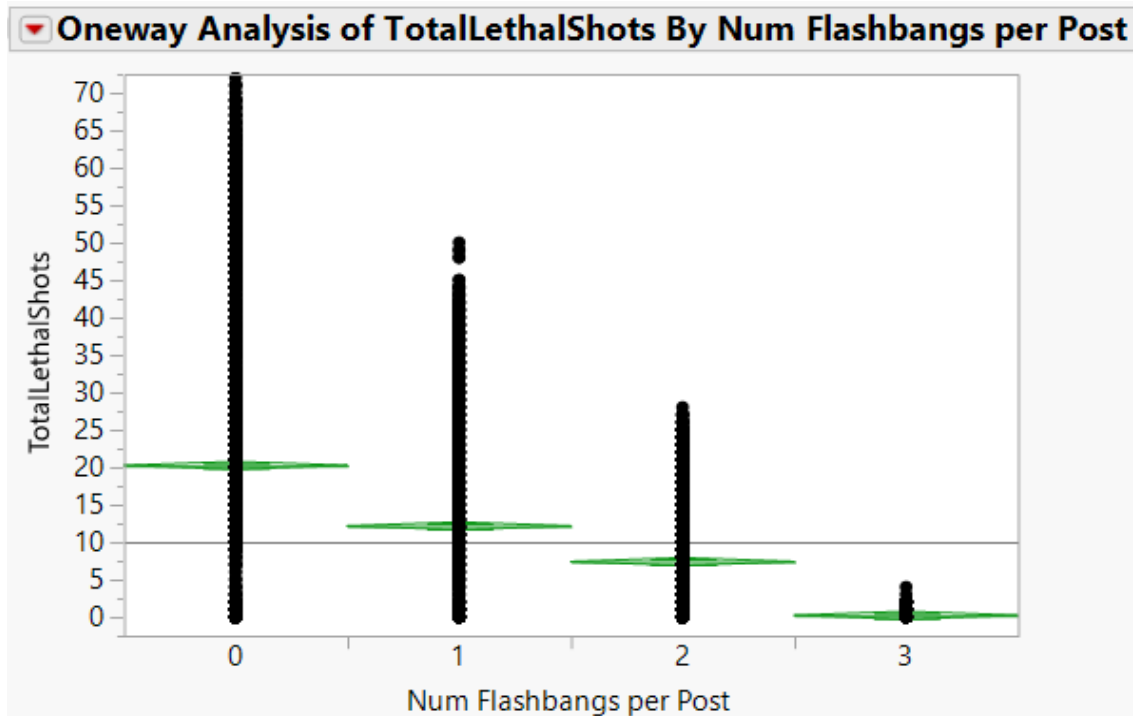
Figure 29. Total Lethal Shots Based on the Number of NLWs per Post.

C. RECOMMENDATIONS

Based on the results and analysis from this research, the following recommendations are made:

- If a minimum engagement range reduction is pursued for the ANLM, it must be reduced to less than 20 meters. Any reduction less than that would have minimal effect on the number of lethal shots fired and gives the warfighter little benefit over current capabilities.

- If intelligence indicates there is a likelihood of a strong contingent of agitators, arm each post with three ANLM capable weapon systems. The mission can be sufficiently conducted with two ANLM capable weapon systems; however, this comes with an increased risk to U.S. personnel.

- If less than 50% of the civilian population is friendly to U.S. forces, arm each post with three ANLM capable weapon systems. The mission can be sufficiently conducted with two ANLM capable weapon systems; however, this comes with an increased risk to U.S. personnel.

D. FUTURE WORK

1. Ammunition Restrictions

This research did not take into account any limitations from ammunition availability that would realistically exist. 40 millimeter grenades are heavy and take up a lot of space; there is a ceiling on how many of these a platoon can carry in conjunction with standard lethal ammunition. If the unit is to carry more non-lethal ammunition, there will likely have to be a trade-off in the amount of lethal ammunition carried. These varying levels can be explored and the ammunition restrictions will likely require ROEs to change based on ammunition load out.

2. Set and Vary Additional Triggers

This model only considers the ROE set forth in Chapter IV. There are many other variations that can be explored. For instance, under certain tactical conditions, Marines can be authorized to use lethal force before lethal force is used on them. To account for this, the level of blue force aggression can be varied and different triggers can be set. This could also determine whether one NLW system employed aggressively is as effective as two systems employed under more restrictive ROE.

3. Supplementary NLW Incorporation

While this research has demonstrated that the ANLM can successfully be employed in securing an embassy, the DOD possesses many other non-lethal capabilities, including non-traditional capabilities such as directed energy. Other NLWs can be incorporated into the model to build a layered non-lethal defense. For example, the ANLM can be used until an agent comes within 75 meters of the entrance, then a directed heat weapon can be used. Layered non-lethal capabilities can yield additional insights into new security postures.

4. Local Force Integration

When securing an embassy, U.S. personnel are seldom authorized to conduct operations off of embassy grounds. This prevents a true defense in depth. To counter this, local forces are often used to conduct security patrols and man posts outside of embassy

grounds. This research does not account for any local force assistance. A new agent class with additional ROEs can be created and implemented into the model to determine how that changes the usage and applicability of NLWs.

5.   Total Population Change

This research did not consider the effect of overall population size, only different ratios of civilians and agitators within the population. It is reasonable to believe the total population size will likely have an effect on the capability of the ANLM; however, one cannot determine to what extent without further experimentation.

6.   Explore Different Variations of Current Settings

There are many variations within the current scenario that can be further explored. The number of Marines per post, the total number of posts, the positioning of the posts, the starting locations of the demonstrators, and many others. By varying additional aspects of the model, the additional sensitivity analysis can further determine the impact and importance of different factors and factor interactions.

7.   Dimensionality

This model takes place in two dimensions. No elevation changes are used, nor are any buildings accessible. In an urban environment, buildings are used extensively to change firing angles, visibility, and concealment. Additionally, right now all terrain that is not explicitly defined as a building or wall is equally traversable. This is not entirely realistic, as roads are more easily traversed than areas with vegetation or other terrain features. This in turn can affect the movement desires of individuals on the ground, making certain avenues of ingress or egress more likely. This dimensionality can be built into the model for additional realism.

APPENDIX. DOD NON-LETHAL WEAPONS DIRECTIVE

Department of Defense
DIRECTIVE

SUBJECT: DOD Executive Agent for Non-Lethal Weapons (NLW), and NLW Policy

References: See Enclosure 1

1.   PURPOSE. This directive:

    a. Reissues DOD Directive (DoDD) 3000.3 (Reference (a)) to update the authority, established policy, and assigned responsibilities for the management of the DOD NLW program.

    b. Continues the designation of the Commandant of the Marine Corps (CMC) as the DOD Executive Agent (EA) for NLW in accordance with DoDD 5101.1 (Reference (b)).

2.   APPLICABILITY. This directive:

    a. Applies to:

        (1) OSD, the Military Departments, the Office of the Chairman of the Joint Chiefs of Staff (CJCS) and the Joint Staff, the Combatant Commands, the Office of the Inspector General of the Department of Defense (IG DOD), the Defense Agencies, the DOD Field Activities, and all other organizational entities within the DOD (referred to collectively in this directive as the "DOD Components").

(2)   All NLW science and technology, development, test and evaluation, assessment of military utility, acquisition programs, operations and sustainment, and the employment of fielded NLW.

(3) NLW that are explicitly designed and primarily employed to incapacitate personnel or materiel immediately, while minimizing fatalities, permanent injury to personnel, and undesired damage to property, facilities, materiel, and the environment.

b. Does not apply to:

(1) Information operations, cyber operations, or any other military capability not explicitly designed and primarily employed to incapacitate personnel or materiel immediately, while minimizing fatalities, permanent injury, and undesirable damage to property, facilities, materiel, and the environment, even though they may have these effects to some extent. Information operations are covered in DoDD 3600.01 (Reference (c)).

(2) Specific electronic warfare (EW) capabilities of electro-optical-infrared and radiofrequency countermeasures; electro-magnetic (EM) compatibility and deception; EM hardening, interference, intrusion, and jamming; electronic masking, probing, reconnaissance, and intelligence; electronics security; EW reprogramming; emission control; spectrum management; and wartime reserve modes, as described in Joint Publication 3–13.1 (Reference (d)).

3.   <u>POLICY</u>. It is DOD policy that:

a. NLW doctrine and concepts of operation will be developed to reinforce deterrence and expand the range of options available to commanders.

b. NLW have the potential to enhance the commander's ability to:

(1) Deter, discourage, delay, or prevent hostile and threatening actions.

(2) Deny access to and move, disable, and suppress individuals.

(3) Stop, disable, divert, and deny access to vehicles and vessels.

(4) Adapt and tailor escalation of force options to the operational environment.

(5) Employ capabilities that temporarily incapacitate personnel and materiel while minimizing the likelihood of casualties and damage to critical infrastructure.

(6) De-escalate situations to preclude lethal force.

(7) Precisely engage targets.

(8) Enhance the effectiveness and efficiency of lethal weapons.

(9) Capture or incapacitate high value targets.

(10)   Protect the force.

c. Unlike conventional lethal weapons that destroy their targets principally through blast, penetration, and fragmentation, NLW employ means other than gross physical destruction to prevent the target from functioning. NLW are intended to have relatively reversible effects on personnel or materiel.

d. NLW are capable of delivering a level of force that achieves immediate target response and can provide predictable and intended reversible effects, allowing the affected target to return to pre-engagement functionality.

e. NLW are developed and used with the intent to minimize the probability of producing fatalities, significant or permanent injuries, or undesired damage to materiel, but do not, and are not intended to, eliminate risk of those actions entirely.

f. Developers of NLW will conduct a thorough human effects characterization in accordance with DOD Instruction (DoDI) 3200.19 (Reference (e)) to help understand the full range of effects and limitations prior to operational employment of the NLW.

g. The availability of NLW will not limit the commander's inherent right or obligation to exercise unit self-defense in response to a hostile act of demonstrated hostile intent, or to use lethal force when authorized by competent authority pursuant to the standing rules of engagement or standing rules for the use of force.

h. The presence of NLW will not constitute an obligation for their use, or create a higher standard for the use of force, under the applicable law, rules of engagement, or other rules for the use of force.

i.   NLW may be used in conjunction with lethal weapon systems to enhance effectiveness and efficiency in military operations, where such use is consistent with domestic and international law, including the laws and customs of war.

j.   Military planners should consider the inclusion of NLW within plans and supporting strategic communications annexes that support minimizing cultural misperceptions, denying misinformation and gaining trust of the populace.

k.   Where appropriate, NLW should be considered for integration into applicable joint and doctrinal publications, joint and Service concept and operational plans, and rules of engagement and rules for the use of force.

4.   <u>RESPONSIBILITIES</u>. See Enclosure 2.

5.   <u>RELEASABILITY</u>. **Unlimited**. This directive is approved for public release and is available on the Internet from the DOD Issuances website at http://www.dtic.mil/whs/directives.

6.   <u>EFFECTIVE DATE</u>. This directive:

a.   Is effective April 25, 2013.

b.   Must be reissued, cancelled, or certified current within 5 years of its publication in accordance with DoDI 5025.01 (Reference (f)). If not, it will expire effective April 25, 2023, and be removed from the DOD Issuances website.

Ashton B. Carter
Deputy Secretary of Defense

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